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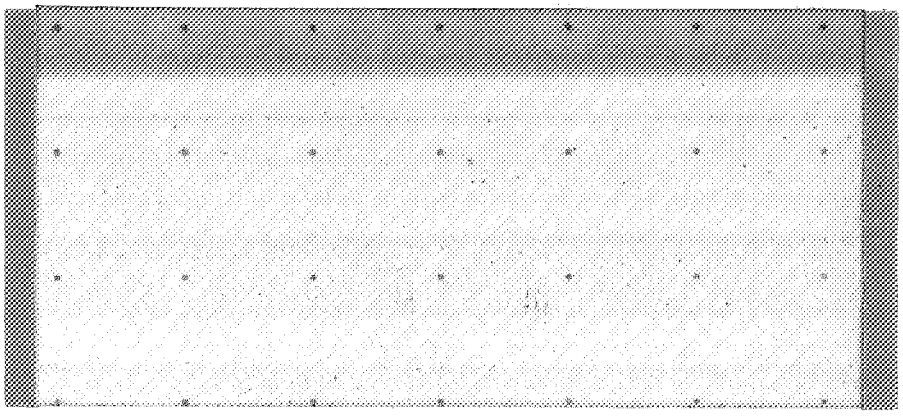

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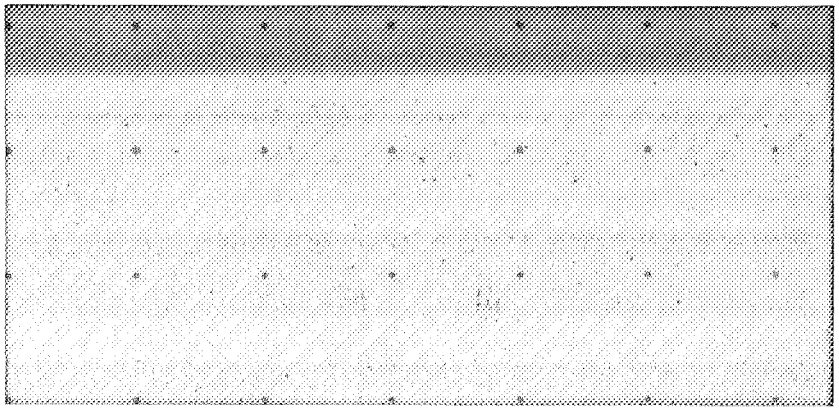

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NASA Contract NAS 5-302

PROJECT APOLLO

A Feasibility Study of an Advanced Manned Spacecraft and System

FINAL REPORT

VOLUME IX. APOLLO PROGRAM IMPLEMENTATION PLAN

CLASSIFICATION CHANGE TO UNCLASSIFIED
By authority of A.E.C. No. 116 52
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Program Manager: Dr. G. R. Arthur
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Prepared for:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Contract NAS 5-302

May 15, 1961

GENERAL ELECTRIC
MISSILE AND SPACE VEHICLE DEPARTMENT
A Department Of The Defense Electronics Division
3198 Chestnut Street, Philadelphia 4, Penna.

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Preface

The APOLLO Program Implementation Plan presents systems the management approach of the General Electric Company for designing, developing, manufacturing and testing the APOLLO space vehicle system and associated ground support equipment. The tasks and schedules presented are based upon the APOLLO space vehicle preliminary design described in the other volumes of this report. Also presented are the General Electric Company corporate management and facility capabilities to support APOLLO, and MSVD experience on other programs which is directly related to APOLLO.

This first edition of the APOLLO Program Plan is organized to permit rapid updating as soon as NASA has selected the specific design and gives the go-ahead on an R&D program. Therefore, this will permit a second ediation of the Program Plan to be prepared within a month of this go-ahead giving immediate program direction to MSVD operations, APOLLO co-contractors, subcontractors and vendors.

CHAPTER I
APOLLO PROGRAM PLAN

CHAPTER I
APOLLO PROGRAM PLAN

1.0 Summary

The National Aeronautics and Space Administration is presently engaged in a program of manned space exploration Project Mercury, currently under way, is the first step in this exploration Project APOLLO, the advanced program of manned space exploration, has been studied by the General Electric Company and is both feasible and practical.

The APOLLO space vehicle, employing the modular concept, will provide an extended earth orbiting laboratory capability with an ultimate objective of manned circumnavigation of the moon and the capability of lunar landings as future growth potential of the APOLLO vehicle is realized

The hardware implementation plan described here covers a span of eight years starting with an assumed contract award in January 1962 and continuing through various phases of development and flight into 1969 Completely qualified flight hardware can be available for manned earth orbital flights by early 1965 and manned circumlunar and lunar orbital flights by 1966 and 1967

Heavy emphasis is placed upon reliability throughout all phases of the program due to the critical nature of the manned APOLLO mission. General Electric Company experience from other programs having stringent reliability requirements, such as the Advent long life communication satellite, has been factored into the APOLLO reliability program.

A comprehensive ground testing program has been developed to provide the APOLLO program with highly reliable hardware, qualified for manned flights This test

program consists of acceptance, development and qualification testing of all components, subsystems and modules as well as the complete APOLLO vehicle. In addition each flight vehicle will be subjected to flight certification tests in space simulators located at the Missile and Space Vehicle Department, Valley Forge facility Each vehicle will be given a complete pre-flight checkout at the AMR facility upon arrival

Early flight of development hardware is considered a necessity for the APOLLO program in order to test equipment under flight environments which cannot be duplicated by ground facilities. Initial flights of development equipment can be accomplished on a non-interference basis starting in mid-1962 in conjunction with various programs such as Atlas, Atlas Agena, Centaur, Titan, Mercury and Saturn. Special APOLLO development flights are planned to provide required environmental data on weightlessness, radiation and re-entry at escape velocity, which are not presently available.

The early phase of the APOLLO vehicle flight program is scheduled to coincide with early flights of Saturn boosters This phase of the flight program is designed to qualify the APOLLO vehicle and its subsystems in flight environments as early as possible using development C-1 boosters This will be approximately one year prior to the time when equipment will be qualified for manned flight

A program of extended orbital flights is planned to provide complete system qualification, evaluation of man's habitability in prolonged space flight, and performance of space laboratory experiments and training missions in such areas as space maneuvering, navigation, rendezvous and docking.

In preparation for the lunar circumnavigation mission, a series of flights will follow the extended orbital flights This series will include manned elliptical earth orbit, cislunar and circumlunar flights

In keeping with the needs of the APOLLO program and its importance to the national space effort, the MSVD APOLLO program will be staffed with a top team of experienced

managerial, scientific and technical personnel The organization proposed places special emphasis on management and systems integration, research, design and development, reliability and test, manufacturing and quality control, field checkout, and the flight program An integral part of the program is the close MSVD coordination with all NASA activities including the Space Task Group, Ames, Lewis, Marshall, Goddard Space Flight Center, and NASA Headquarters This coordination will emphasize factoring NASA technical capability into design and development of the APOLLO System

2.0 Objectives, Requirements and Schedules

2.1 PROGRAM OBJECTIVES

2.1.1 The purpose of this program is manned exploration of space.

The primary objective is to perform extended earth-orbital missions with an ultimate objective of manned circumnavigation of the Moon and the capability for lunar landings as future growth potential of the APOLLO vehicle. To accomplish this objective the following areas of work will be accomplished.

2.1.1.1 Design, development and demonstrate by test the APOLLO space vehicle, ground support equipment, and vehicle subsystems which will meet the requirements of the APOLLO System. This development and testing shall be compatible with the NASA Space Task Group Master Phasing Schedule so that the MSVD portions of the system will be available on the required R & D flight test dates.

2.1.1.2 The R & D program shall be so organized, planned and accomplished as to permit a completely integrated, interwoven functional accomplishment in order that the evolution of designs, demonstration tests, and supporting plans will each reflect the maximum amount of timely incorporation of these benefits to the APOLLO Program.

2.1.1.3 Studies and analysis shall be initiated and updated during the R & D program based upon NASA direction and MSVD technical advancements. Digital and analogue equipment shall be employed as required for this purpose. Such studies shall reflect experience gained from other current programs within and outside of MSVD. Preliminary test models shall be established for confirmation of state-of-the-art techniques as well as confirmation of values used in preliminary studies.

In this manner, it is anticipated that the basic development effort will result in an immediate prediction of APOLLO equipment configuration, thereby permitting

adjacent technologies to develop their skills around a partially but technically sound design. As these adjacent technologies, each in turn, reach the same degree of comparative position of skill the resulting design will be re-evaluated as a subsystem and correlated with associated subsystems to permit the integrated evaluation of the complete preliminary vehicle system. The BEST program will facilitate such a technique.

2.1.1.4 An integrated test program shall be implemented throughout the APOLLO development cycle. This test program will be coordinated with the customer to eliminate duplication of identical tests, to share responsibilities, and to alter test objectives as required. Certain tests shall be exploratory in nature for the purpose of investigation and evaluation, and will become the basis for justification of the design and parametric trade-offs. Other tests shall be performed subsequent to design to verify equipment integrity and compliance with contractual requirements.

2.2 PROGRAM REQUIREMENTS

2.2.1 The APOLLO space vehicle will weigh nominally 15,000 lb. and be the D-2 configuration. It shall be compatible for launching from both the Saturn C-1 and C-2 rocket boosters.

2.2.2 MSVD shall design and develop the APOLLO vehicle to perform an extended manned earth orbital mission with its ultimate objective manned lunar orbital flights.

2.2.3 On the APOLLO Program, GE-MSVD shall be a prime contractor to the NASA Space Task Group. MSVD shall have complete responsibility for the integrity of the APOLLO vehicle and all items of Ground Support Equipment (GSE) peculiar to the handling, support, test, maintenance and inspection of the space vehicle.

2.2.4 MSVD shall deliver space vehicles, mock-ups and separate space vehicle subsystems in accordance with the delivery schedule given in Figure I-2-2. MSVD shall maintain on a current basis the necessary mock-ups for the APOLLO vehicle.

2.2.5 MSVD shall deliver GSE in accordance with the delivery schedule given in Figure I-2-2.

2.2.6 MSVD shall have prime responsibility for the formulation and conduct of the ground test program for the APOLLO space vehicle.

2.2.7 MSVD shall provide senior technical representatives to support System Development and Test Planning Committees.

2.2.8 MSVD shall provide training hardware and manuals as required to support the APOLLO Program.

2.2.9 MSVD shall be responsible for field checkout and preparation of all space vehicles for the APOLLO R & D Program.

2.2.10 MSVD shall prepare and submit to the NASA Space Task Group technical and status reports as listed in Section 3-7.

2.2.11 MSVD shall implement and maintain the Budget Evaluation and Scheduling Technique (BEST), which is a modified PERT system. Detail networks shall be prepared of selected events which are sequential and lead to the program objectives of manned lunar flights.

2.2.12 Throughout the entire development cycle, a positive reliability program will be established to run concurrently with hardware development. In this manner reliability will be factored into design, measured during R & D testing, maintained and controlled during fabrication and use, and predicted continually throughout the program.

2.3 PROGRAM SCHEDULES

Figures I-2-1 through I-2-10 presents the APOLLO Hardware Implementation Program Schedules to accomplish the program requirements previously defined.

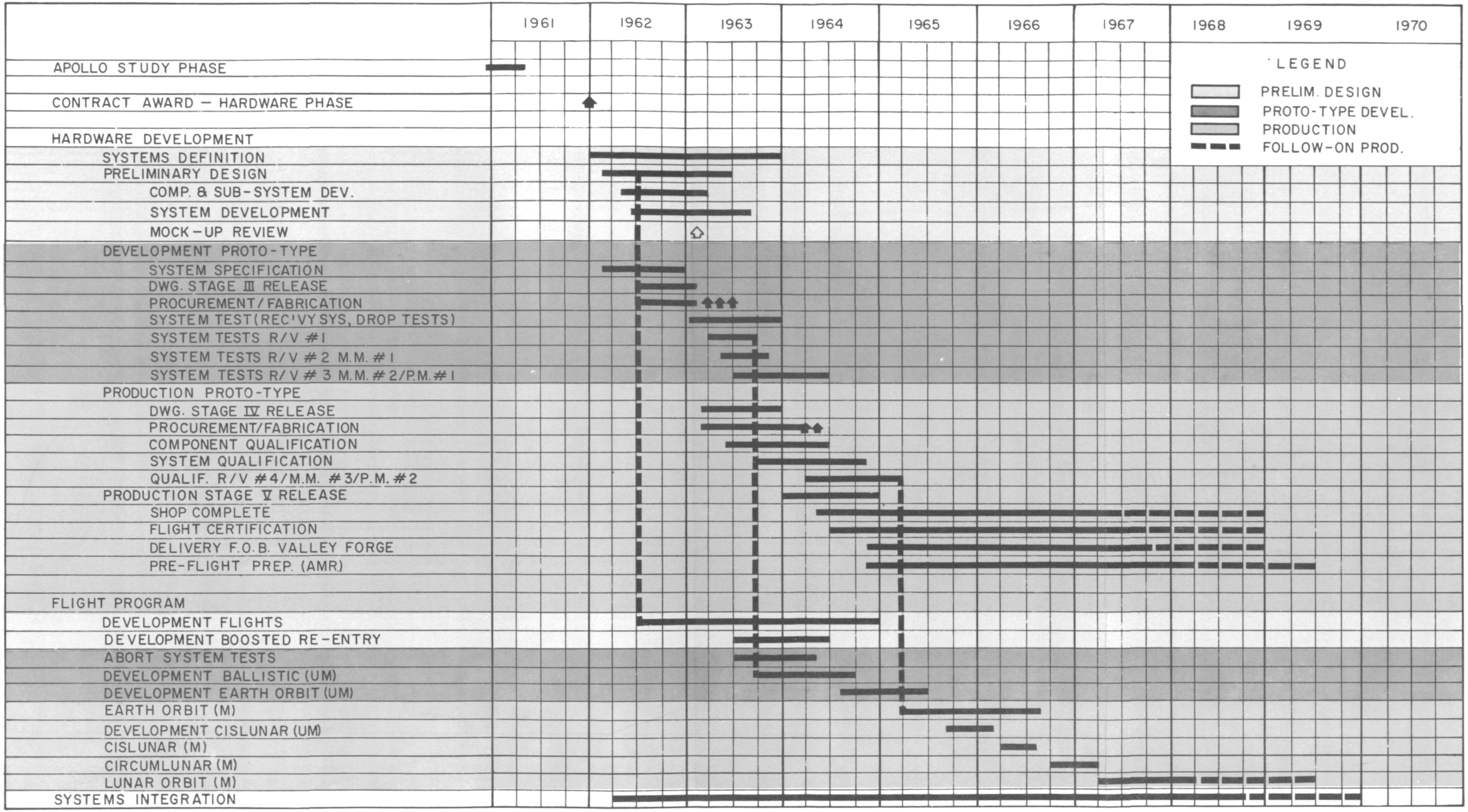

Figure I-2-1. APOLLO hardware program plan

MAJOR KEY EVENTS

- CONTRACT AWARD
- SYSTEM SPECIFICATIONS
- START STAGE 3 DRAWING RELEASE
- START STAGE 4 DRAWING RELEASE
- START SYSTEMS TEST D-1
- START COMPONENT QUALIFICATION
- START SYSTEMS TEST D-2
- UNMANNED BALLISTIC FLIGHT
- START QUAL. TESTS Q1
- COMPLETE SYSTEMS TEST D-2
- START FLIGHT CERTIFICATION
- UNMANNED EARTH ORBIT
- START PROD. SPACECRAFT DEL
- STAGE 5 DRAWING RELEASE
- MANNED EARTH ORBITAL FLIGHT
- MANNED CISLUNAR FLIGHT
- MANNED ELLIPTICAL ORBIT FLIGHT
- MANNED CIRCUMLUNAR FLIGHT
- MANNED LUNAR FLIGHT

TIME FROM GO-AHEAD: 1962 | 1963 | 1964 | 1965 | 1966 | 1967

RELIABILITY PROGRAM

RELIABILITY ATTAINMENT
- APPORTIONMENT OF RELIABILITY GOALS
- FIGURE OF MERIT STUDIES
- DES REVIEW
- DES REVIEW
- DES REVIEW
- DES REVIEW
- DES REVIEW

RELIABILITY MEASUREMENT AND ANALYSIS
- SYSTEM INTEGRATED TEST PROGRAM BOARD
- PREDICTION STUDIES
- PARTS TESTING AND SELECTION - LONG LIFE
- MEASUREMENT OF REL GROWTH
- COMPONENT QUALIFICATION
- FAILURE REPORTING ANALYSIS AND CORRECTIVE ACTION
- SYSTEMS QUALIFICATION
- EQUIPMENT RELIABILITY STATUS REPORT

RELIABILITY MAINTENANCE
- MAKE OR BUY
- VENDOR SURVEYS
- VENDOR RATING
- VENDOR REQMTS AND SPECS
- VENDOR PERFORMANCE MEASUREMENT
- FLIGHT CERTIFICATION TESTING

DESIGN PROGRAM

PRELIMINARY DESIGN
- PROGRAM PLAN
- SUB-SYSTEM BLOCK DIAGRAM
- PRELIM. REPORT (INTERFACE)
- DESIGN FREEZE
- MOCK-UP COMPLETE

BREADBOARD TESTS
- SUB-SYSTEM BUILD-UP
- SUB-SYSTEM TESTS

COMPONENT DESIGN
- STAGE 1
- STAGE 2
- STAGE 3
- STAGE 4
- P.O'S COMPLETE
- TEST COMPLETE
- STAGE 5

SYSTEM DESIGN
- SYSTEM SPEC.
- STAGE 1
- STAGE 2 DESIGN FREEZE
- STAGE 3
- STAGE 4
- STAGE 5

QUALIFICATION
- START LIFE TESTS
- START COMPONENT TESTS
- SYSTEM EVAL TEST PLAN
- START SYS. TEST
- COMPLETE COMPONENT TESTS
- SYS. TEST COMPLETE
- COMPONENT AND SYSTEM CERTIFICATION

STAGE RELEASE DEFINITIONS

STAGE	COMPONENT	SUB-SYSTEM
1	• FORM FACTOR • MAXIMUM DIMENSIONS, POWER, THERMAL OUTPUT LOCATION, ORIENTATION • ACCESSIBILITY REQUIREMENTS • TEMPERATURE LIMITS	• BLOCK DIAGRAMS • TELEMETRY REQUIREMENTS, MAXIMUM • NOISE REQUIREMENTS • RELIABILITY REQUIREMENTS • ACCEPTANCE TEST REQUIREMENTS - PRELIMINARY
2	• EXTERNAL CONFIGURATION, CONNECTOR LOCATIONS, MOUNTING ARRANGEMENT, DIMENSIONS, POWER REQUIREMENTS, THERMAL OUTPUTS TO ±10% • RELIABILITY REQUIREMENTS • CONNECTOR TYPES • BONDING AND SHIELDING REQUIREMENTS	• PRELIMINARY SCHEMATICS • TELEMETRY REQUIREMENTS • ACCEPTANCE TEST REQUIREMENTS • PRELIMINARY FLIGHT TEST REQUIREMENTS • GROUNDING AND SHIELDING REQUIREMENTS
3	• OUTLINE DRAWING TO MANUFACTURING TOLERANCES • COMPLETE INTERFACE RESOLUTION • ADEQUATE FOR ADVANCE ORDER	• SCHEMATICS • HANGAR TEST REQUIREMENTS • FLIGHT TEST REQUIREMENTS • COMPLETE INTERFACE RESOLUTION
4	• SPECIFICATION • SPECIFICATION CONTROL DRAWING	• SPECIFICATIONS • WIRING DIAGRAMS
5	• COMPONENT BUY-OFF AND CERTIFICATION	• SUB-SYSTEM BUY-OFF AND CERTIFICATION

TEST PROGRAM

DEVELOPMENT
- BREADBOARD
- COMPONENT SYSTEMS
- D-1
- DESIGN VERIFICATION

COMPONENT QUALIFICATION
- FUNCTIONAL AND ENVIRONMENT TESTING

SYSTEM EVALUATION
- D-2
- ENG. EVALUATION & CREW TRAINING
- DROP TEST, PROPULSION, LIFE SUPPORT, ETC.

SYSTEM QUALIFICATION
- X-1, X-2, X-3, X-4, D-1
- ABORT SYSTEM EVALUATION
- ENG'R. DESIGN VERIFICATION
- DF-1, DF-2, DF-3, DF-4, DF-5

SPACECRAFT QUALIFICATION
- DF-7, DF-8, DF-10
- EARTH ORBIT
- Q-1, Q-2
- QUALIFICATION TESTING
- D-3
- ENG'R. DESIGN VERIFICATION

FLIGHT CERTIFICATION
- PRODUCTION CERTIFICATION

CREW TRAINING
- CREW TRAINING (FLIGHT & GROUND)
- MANNED LUNAR

FLIGHTS
- EARTH ORBIT, CISLUNAR, CIRCUMLUNAR

MFG & QC & T DEVELOPMENT HARDWARE

D-1	DESIGN VERIFICATION	FAB & ASSY — ENG DESIGN VERIFICATION
D-2	DESIGN VERIFICATION	FAB & ASSY — SYSTEM EVAL — CREW TRAINING
X-1	PAD ABORT	FAB & ASSY — QC & T
X-2	PAD ABORT	FAB & ASSY — QC & T
X-3	FLIGHT ABORT	FAB & ASSY — QC & T
X-4	FLIGHT ABORT	FAB & ASSY — QC & T
DF-1	BALLISTIC	FAB & ASSY — QC & T
DF-2	BALLISTIC	FAB & ASSY — QC & T
D-3	DESIGN VERIFICATION	FAB & ASSY — ENGINEERING DESIGN VERIFICATION
DF-3	BALLISTIC	FAB & ASSY — QC & T
DF-4	BALLISTIC	FAB & ASSY — QC & T
DF-5	ABORT POWERED FLIGHT	FAB & ASSY — QC & T
DF-6	BALLISTIC HIGH ALT	FAB & ASSY — QC & T
DF-7	EARTH ORBIT (CIR)	FAB & ASSY — QC & T
DF-8	EARTH ORBIT (CIR)	FAB & ASSY — QC & T
DF-10	EARTH ORBIT (ELLIP)	FAB & ASSY — QC & T
Q-1	QUALIFICATION	FAB & ASSY — ASSY TEST — PROD SPACECRAFT QUALIFICATION
Q-2	QUALIFICATION	FAB & ASSY — ASSY TEST — SAME AS Q-1

GROUND SUPPORT EQUIPMENT

GSE 1	SYSTEM DEVEL	FAB ASSY AND TEST — DEVELOPMENT, EVALUATION & QUALIFICATION TESTING
GSE 2	QUALIFICATION	FAB ASSY AND TEST — SPACECRAFT QUALIFICATION TESTING
GSE 3	ACCEPTANCE	FAB ASSY AND TEST — FLIGHT CERTIFICATION TESTING
GSE 4 & 5	HANGER	FAB ASSY AND TEST (PARTIAL) — FAB ASSY AND TEST (FULL) — INSTALLATION — SPACECRAFT HANGER CHECKOUT
GSE 6 & 7	LAUNCH PAD	FAB ASSY AND TEST (PARTIAL) — FAB ASSY AND TEST (FULL) — INSTALLATION — SPACECRAFT LAUNCH PAD CHECKOUT

Figure I-2-2. Integrated program schedule

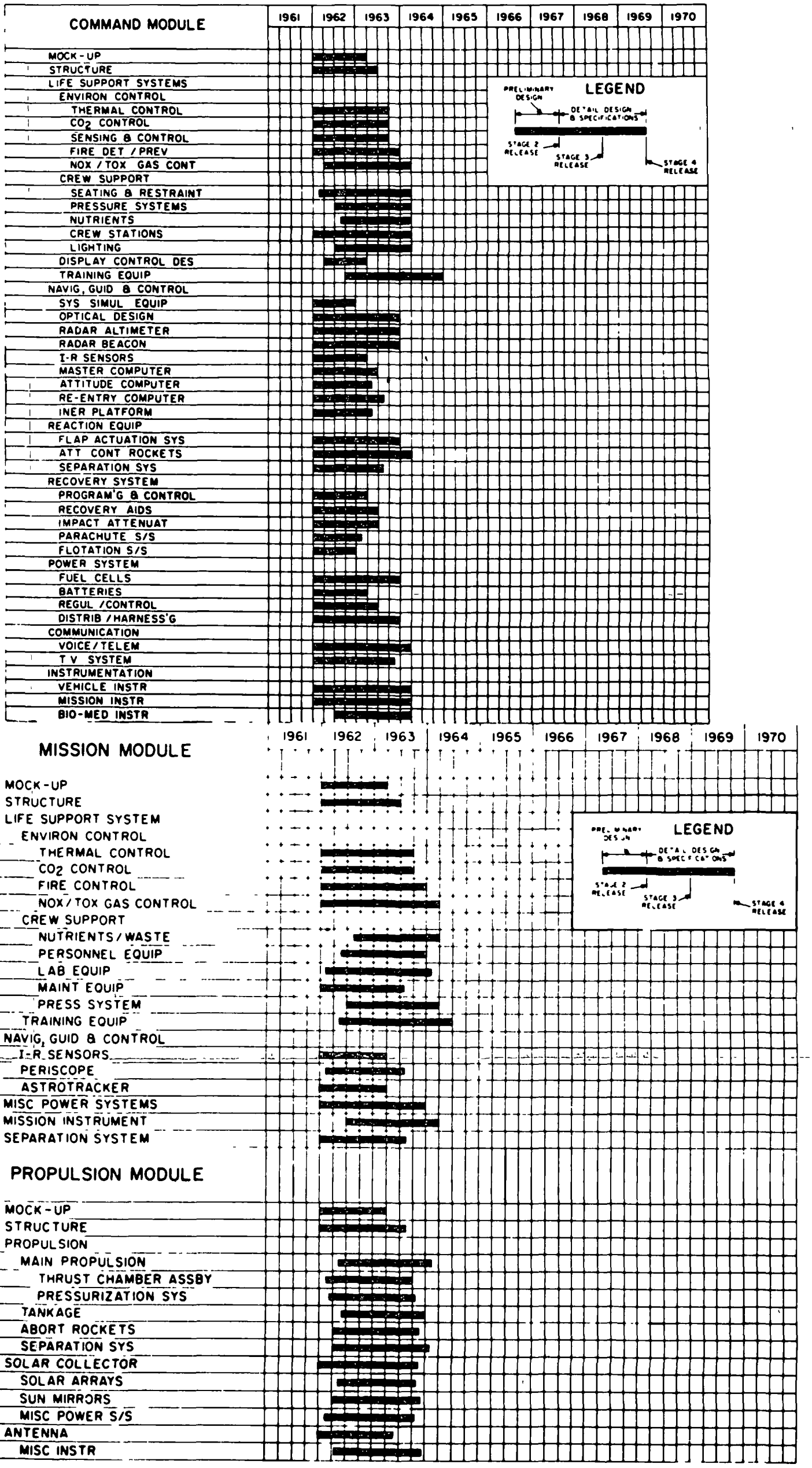

Figure I-2-3. Engineering schedule

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PRELIMINARY DESIGN TESTS

1961 | 1962 | 1963 | 1964 | 1965

I. VEHICLE DESIGN & DEVELOPMENT
- A. Material Development
  - 1. L Area Bonding Structure Test
  - 2. Temperature Tests
  - 3. Plastics Structure – Outgassing Tests
  - 4. Ablation Tests – Rocket Exhaust
  - 5. Inflatable Solar Collector Tests
  - 6. Optic Tests
  - 7. Wind Tunnel & Shock Tunnel Tests
- B. Protection Systems
  - 1. Thermal Protection Tests
  - 2. Solar Radiation Tests
  - 3. Meteroid Bumper Tests
  - 4. Structure & Ablation Repair Tests
  - 5. Access Pressure Ports Tests
- C. Separation Systems
  - 1. L Wt., L Dia. Shaped Charge Tests
  - 2. L Wt., L Dia. Mech.
- D. Recovery & Landing Systems
  - 1. Lab Drop Tests
  - 2. Retardation Devices & Control Surfaces Tests
  - 3. Wind Tunnel & Wake Survey
  - 4. Impact Attenuation
- E. Advanced Fabrication Techniques
  - 1. L Bonded Structure Tests
  - 2. Beryllium Structure Development Tests
  - 3. Sandwich/Foam Structure Tests

II. LIFE SUPPORT DEVELOPMENT
- A. Crew Functions Development
  - 1. Display Development Tests
  - 2. Work-Rest Cycle Tests
  - 3. Training Req Checkout
  - 4. Personnel Maintenance Cap Tests
  - 5. KC–135 Zero "G" Tests
- B. Biological Requirements
  - 1. Acceleration Tests
  - 2. Vib-Acoustic Noise Tests
  - 3. Food-Water-Waste Test
  - 4. Space Suit Tests
  - 5. Visual Tests

1961 | 1962 | 1963 | 1964 | 1965

III. TELEMETRY – RECORDERS
- 1. Thermo Plastic Recorder Tests
- 2. PCM/FM Encoder Tests
- 3. 2 Watt, 2 KMC Rec-Trans Tests

IV. INSTRUMENTATION
- A. Vehicle Instrumentation
  - 1. Sensor Tests
  - 2. Control Instruments Test
  - 3. Communication Instruments (Recording) Tests
- B. Mission Instrumentation
  - 1. Photo Tests
  - 2. Customer Equipment Tests
  - 3. Television Equipment Tests
- C. Biological
  - 1. Cabin Environmental Tests
  - 2. Biological Instrumentation

V. NAVIGATION, GUIDANCE & CONTROL
- A. Propulsion Systems
  - 1. Attitude Control Propulsion Tests
  - 2. Abort Rocket Propulsion Tests
  - 3. On Board Propulsion Tests
- B. Astro Navigation
  - 1. Astro Tracker Tests
  - 2. Computer Tests
  - 3. IR Sensor Tests
  - 4. Sun Tracker Tests
  - 5. Radar Altimeter Tests
- C. Guidance & Control System
  - 1. Control System Tests
  - 2. Radar Beacon Tests
- D. Stabilization System
  - 1. Stable Platform Tests

1961 | 1962 | 1963 | 1964 | 1965

VI. ELECTRICAL POWER & DISTRIBUTION
- A. Solar Collector Testing
  - 1. Inflatable Balloon Tests
  - 2. Solar Cells Tests
  - 3. Collector Filters Tests
- B. Power Generation Testing
  - 1. Regenerative Fuel Cell
    - Single Cell Cycle Tests
    - Multi Cells Cycle Tests
    - Module Life Tests
- C. Power Control Testing
  - 1. L Wt. – Heavy Power Circuit Tests
  - 2. Switching Elements
    - Special Environments
- D. Power Storage Testing
  - 1. Storage Battery Tests
  - 2. Emergency Storage Power

VII. COMPONENT DEVELOPMENT
- A. Functional
  - 1. Pre-Prototype Tests
  - 2. Prototype Tests
- B. Environments
  - 1. Environments Tests

Figure I-2-4.1. Test program schedules - Ground

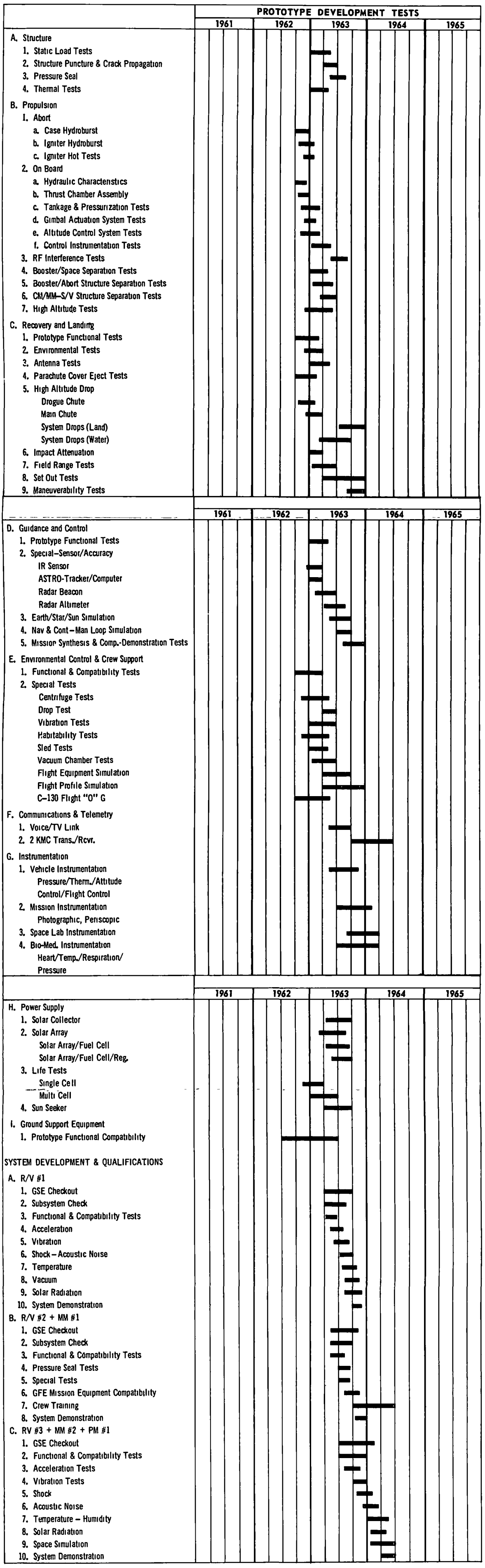

Figure I-2-4.2. Test program schedules - Ground

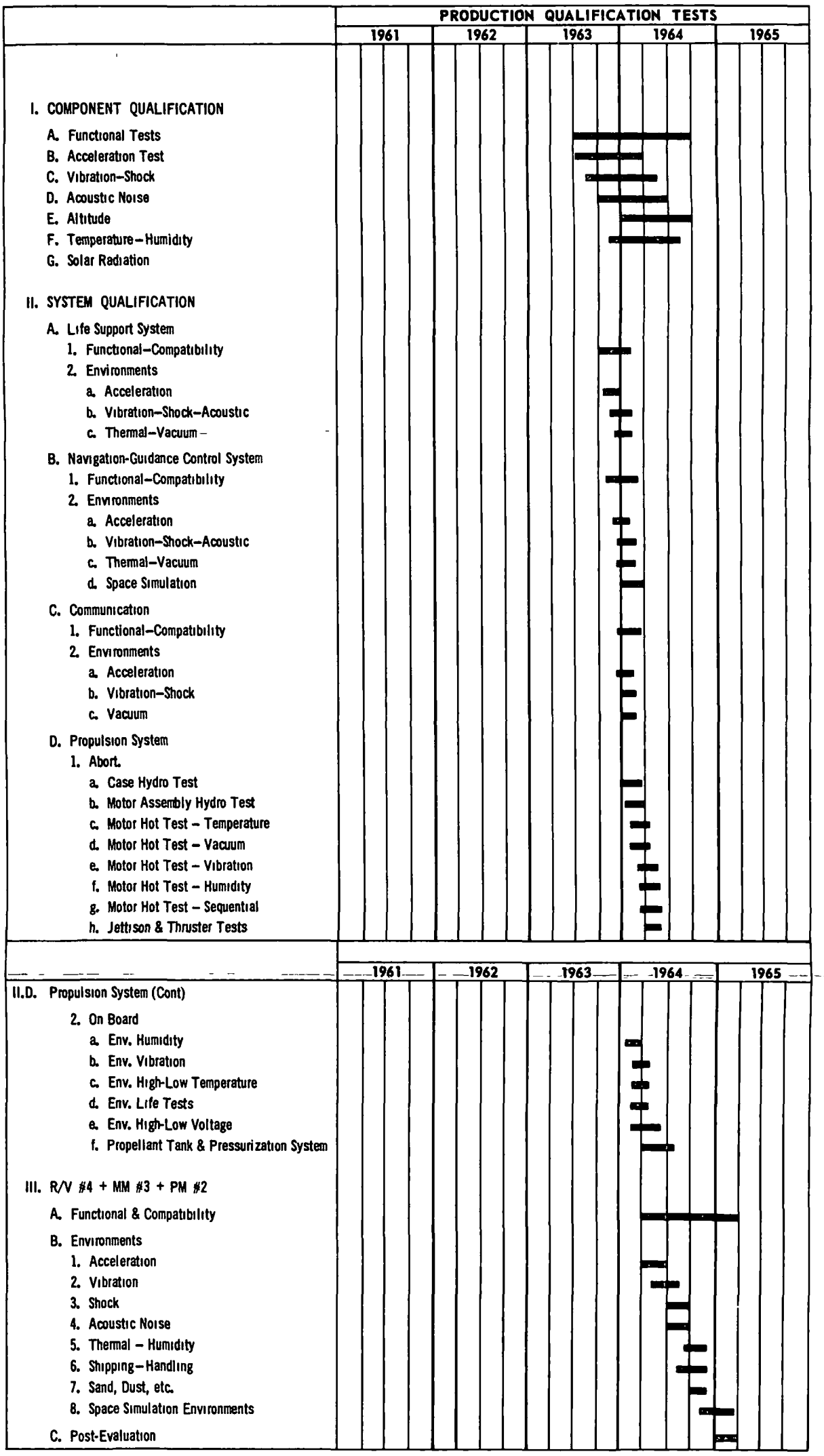

Figure I-2-4.3. Test program schedules - Ground

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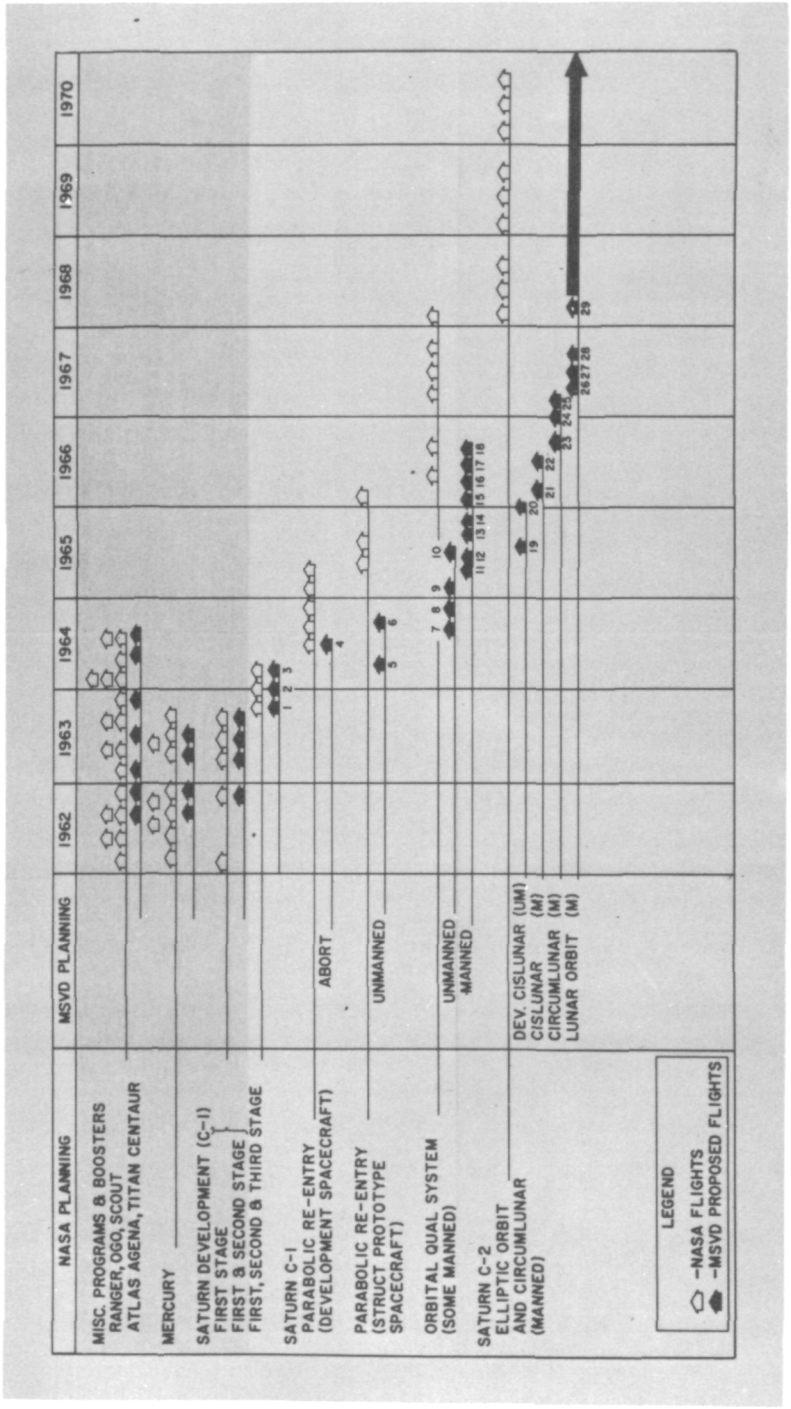

Figure I-2-5. Integrated flight schedule

FLIGHT NO.	PROGRAM/BOOSTER: MERCURY	RANGER	OGO	SCOUT	ATLAS/AGENA	TITAN	CENTAUR	SATURN (D)	SIM GRD FACILITY	SPECIAL BOOSTER MAX Q ABORT	ATLAS X254	FLIGHT ENVIRON	PURPOSE		1962	1963	1964
1		✓		✓								HIGH ALT BALLISTIC OR DEEP SPACE PROBE	G & C COMPONENTS	IR SENSOR SUN TRACKER	●		
2	✓				✓								G & C SUB-SYSTEM LIFE SUPPORT COMPONENT	RADAR ALTIMETER ASTRO TRACKER & COMPUTER, ATTITUDE CONTROL LOX CONVERTER, WATER RECOVERY, GASEOUS SENSOR, LEAK DETECTOR, CO^2 REMOVAL	●		
3	✓				✓							BALLISTIC AND/OR EARTH ORBIT ("0" G ENVIRONMENT)			●		
4	✓				✓											●	
5						✓	✓	✓				BALLISTIC	G & C DEV SYSTEM	G & C SYSTEM IR SENSOR, SUN TRACKER, ASTRO TRACKER, COMPUTER, RAD ALT, ATT CONT	●		
6						✓	✓	✓								●	
7						✓	✓	✓								●	
8	✓											EARTH ORBIT (MAN IN SYSTEM "0"G)	TEL COMM SYSTEM LIFE SUPPORT COMPONENTS & SUB-SYSTEMS	THERMO-PLAS REC PCM/FM ENC LOX CONVERTER, WATER RECOVERY, CO^2 REMOVAL, GASEOUS SENSOR, MAN SENSORS		●	
9	✓															●	
10			✓	✓	✓		✓					BALLISTIC EARTH ORBIT ELLIP EARTH ORBIT SPACE PROBES	MISC COMPONENTS & SUB-SYSTEMS	TELEMETRY, COMMUNICATION, MATERIALS, LIFE SUPPORT, BIO-MED RAD, PROPELLENT- SENSOR		●	
11			✓		✓		✓									●	
12			✓	✓	✓		✓									●	
13			✓		✓	✓	✓									●	
14			✓		✓	✓	✓									●	
15									✓			PAD ABORT	ABORT SYSTEM RECOVERY SYSTEM	BOILER PLATE HARDWARE, INSTRUMENTATION REC SYSTEM		●	
16									✓			PAD ABORT				●	
17										✓		MAX Q ABORT	ABORT SYSTEM RECOVERY SYSTEM	ABORT SENSING, GROUND TRNG		●	
18										✓		MAX Q ABORT				●	
19				✓	✓						✓	BOOSTED RE-ENTRY	ENVIRONMENT IDENTIFICATION			●	
20				✓	✓						✓	BOOSTED RE-ENTRY				●	
21					ATLAS ✓							RE-ENTRY	CONFIG SUBSTANTIATION	RVX-2A FWT WITH MODELS	●		

Figure I-2-6. Development flight program schedule

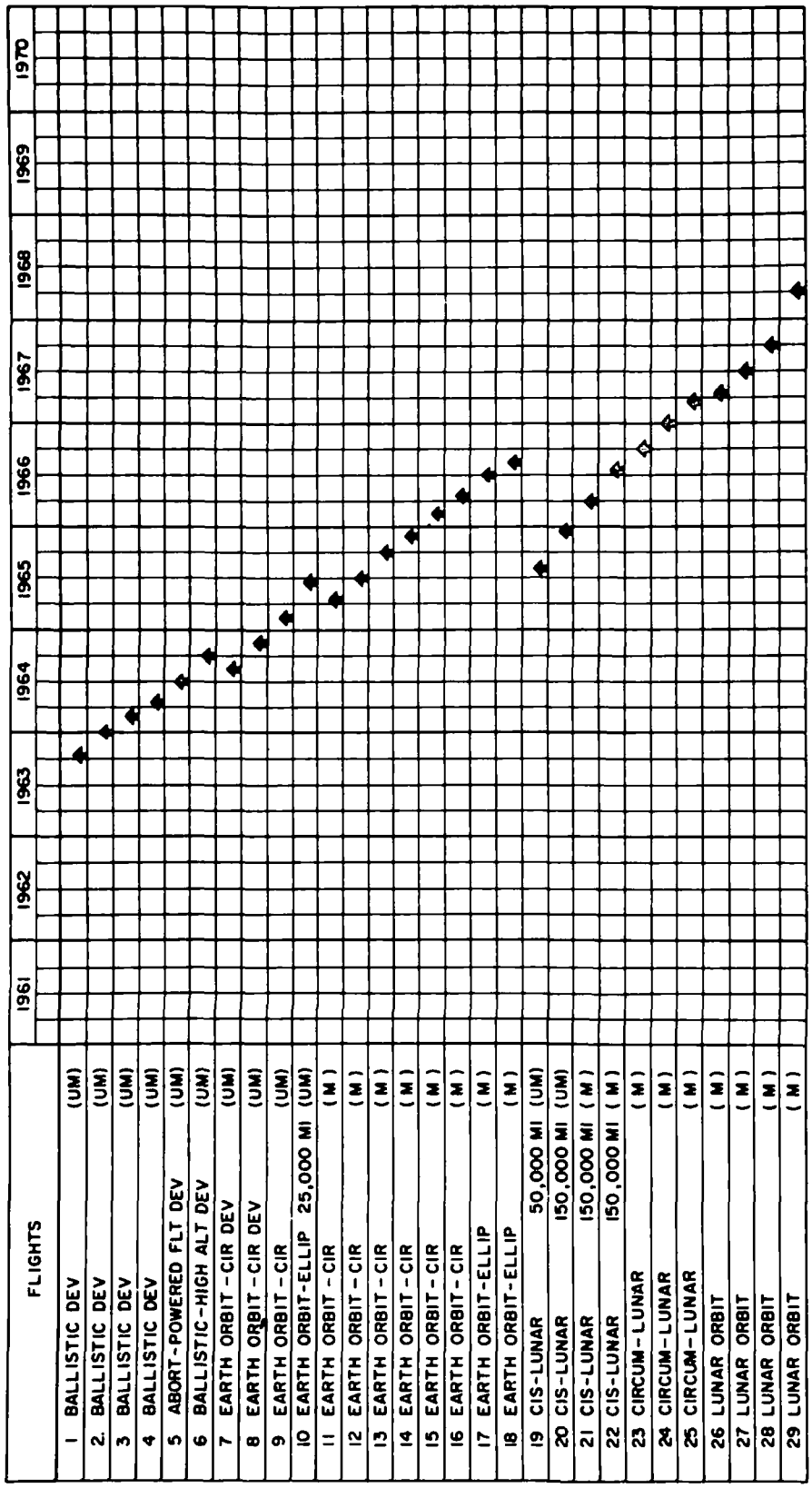

Figure I-2-7. APOLLO/Saturn flight schedule

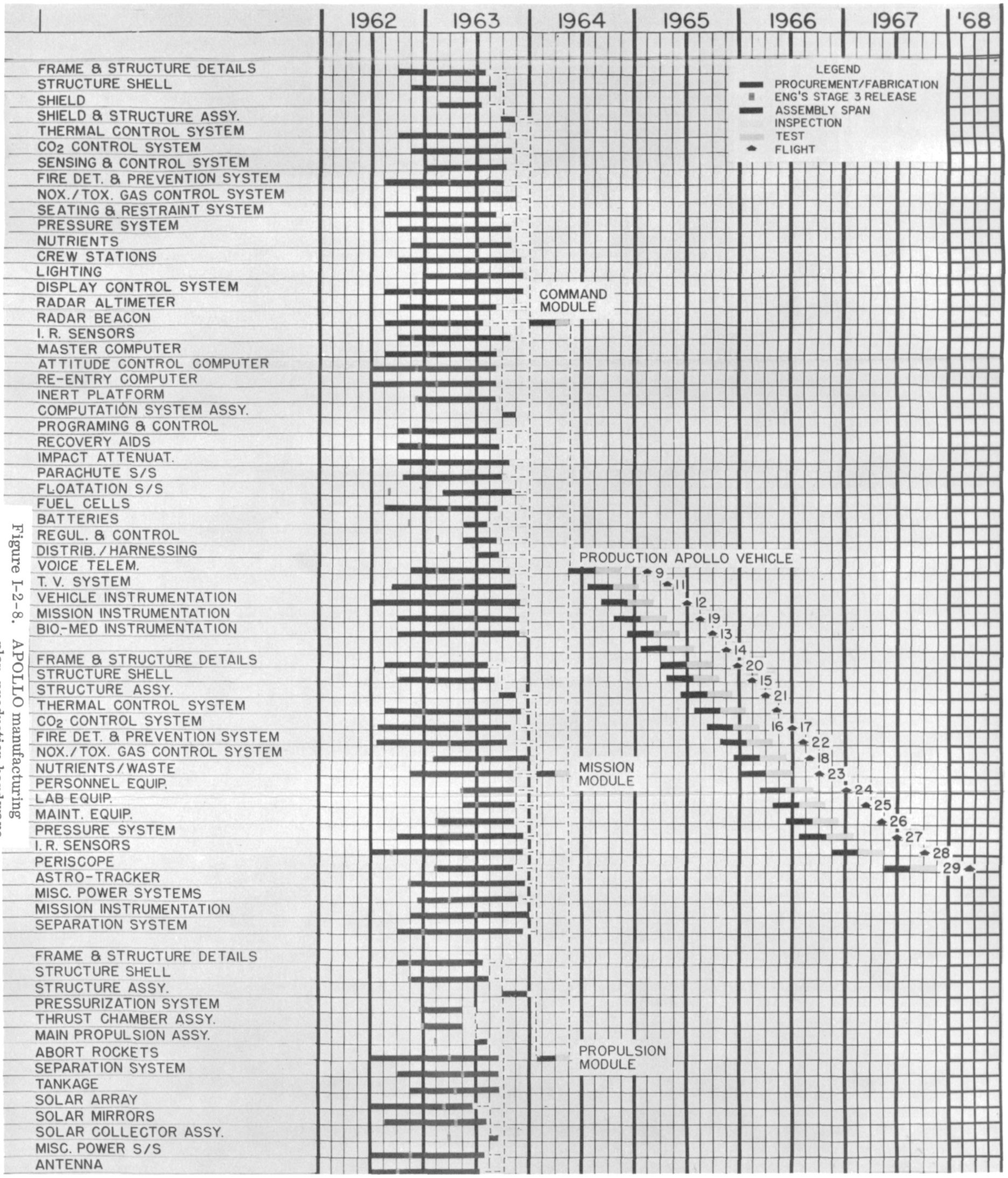

Figure I-2-8. APOLLO manufacturing plan-production hardware

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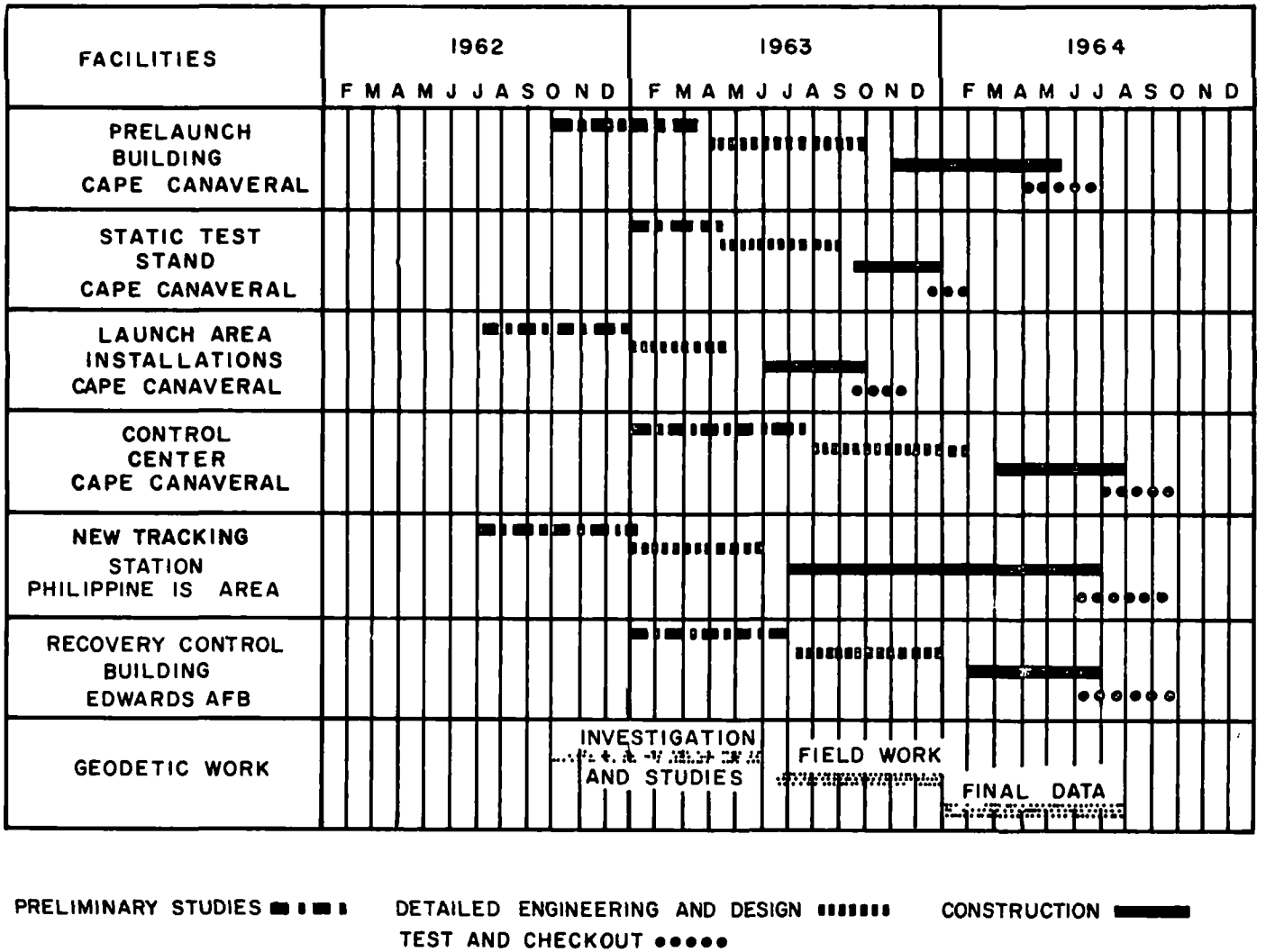

Figure I-2-9. Field facility implementation schedule

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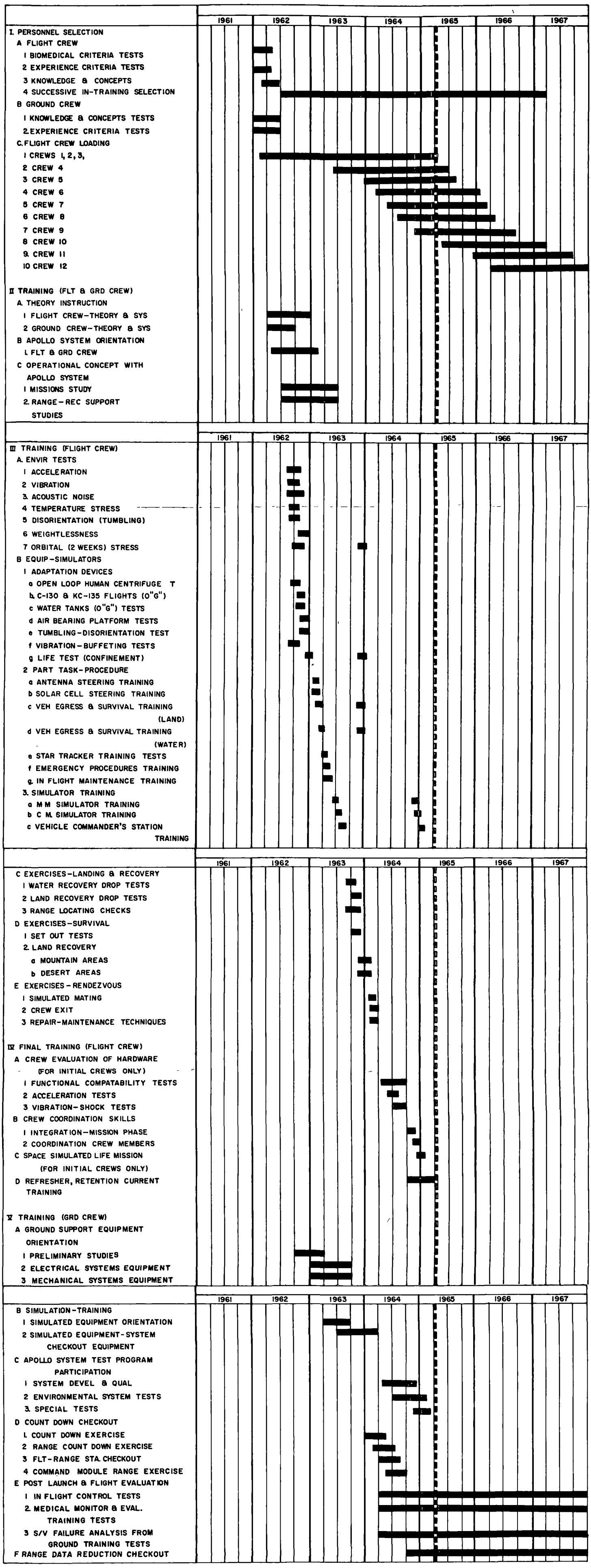

Figure I-2-10. Training and indoctrination schedule

3.0 Program Management and Systems Integration

The complexity of the APOLLO research and development program requires strong, effective systems integration. In order to perform adequate systems management and provide technical direction to responsible operations it is necessary to have one focal point for the APOLLO program in MSVD, the APOLLO program office. The APOLLO program office will be organized as shown in Figure I-3-1.

The APOLLO program office will interpret the NASA program requirements, establish program objectives, assign authority and responsibility, provide adequate funding, and monitor and evaluate performance against detailed work schedules both internal and with all sub-contractors.

The APOLLO program office will have seven functional groups reporting to the APOLLO Program Manager as shown in Figure I-3-1. These are:

1. APOLLO Systems Integration
2. APOLLO Engineering
3. APOLLO Quality Control
4. APOLLO Manufacturing
5. APOLLO Test Integration and Reliability
6. APOLLO Field/Flight Operation
7. APOLLO Program Control

Figure I-3-2 illustrates the organizational relationships between NASA, MSVD, co-contractor, subcontractor, government ranges, etc. and the technical areas which will require integration.

Within MSVD, integration is accomplished by means of the Program Plan, which is described in Section 3.1. Outside MSVD there are four major groups which must be integrated:

1. NASA

   Integration with NASA will include technical review, direction and status reporting. Technical reviews will be conducted on a periodic basis. Specific agenda items related to current issues as well as planning sessions will be conducted. Technical direction will be accepted from the NASA Space Task Group for all NASA activities. This direction will be included in the Program Plan, applicable test and/or flight plans and in the System Specification. Written Program status reports will be submitted periodically. This will include schedules and budgets as well as problem areas. Oral status reports will be presented to NASA quarterly.

2. CO-CONTRACTORS

   Integration with co-contractors will be accomplished by means of the Joint Operating Plan. This document spells out the method of operation between MSVD and the co-contractor and will include schedules, signed-off interface drawings, interface agreements and participation with co-contractor in countdown. Fixtures will be provided to the co-contractor of the upper stage booster for duplicating vehicle interface. An APOLLO vehicle will be mounted on the upper stage of the booster for static firing. Joint participation with the co-contractor will be provided for program status reviews.

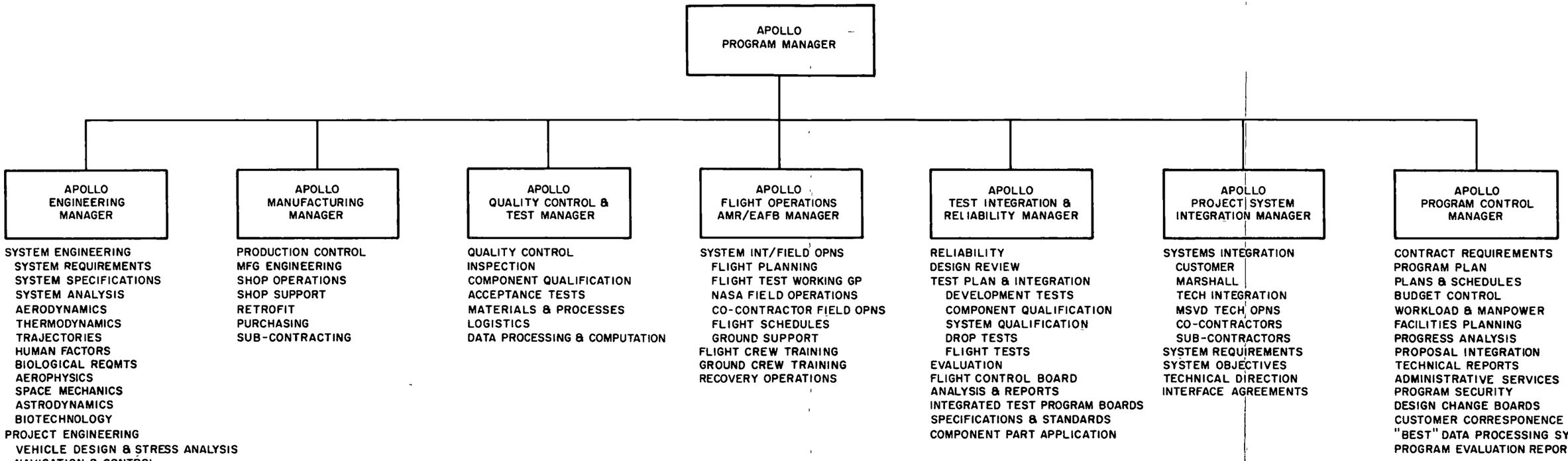

Figure I-3-1. APOLLO program office functional organization

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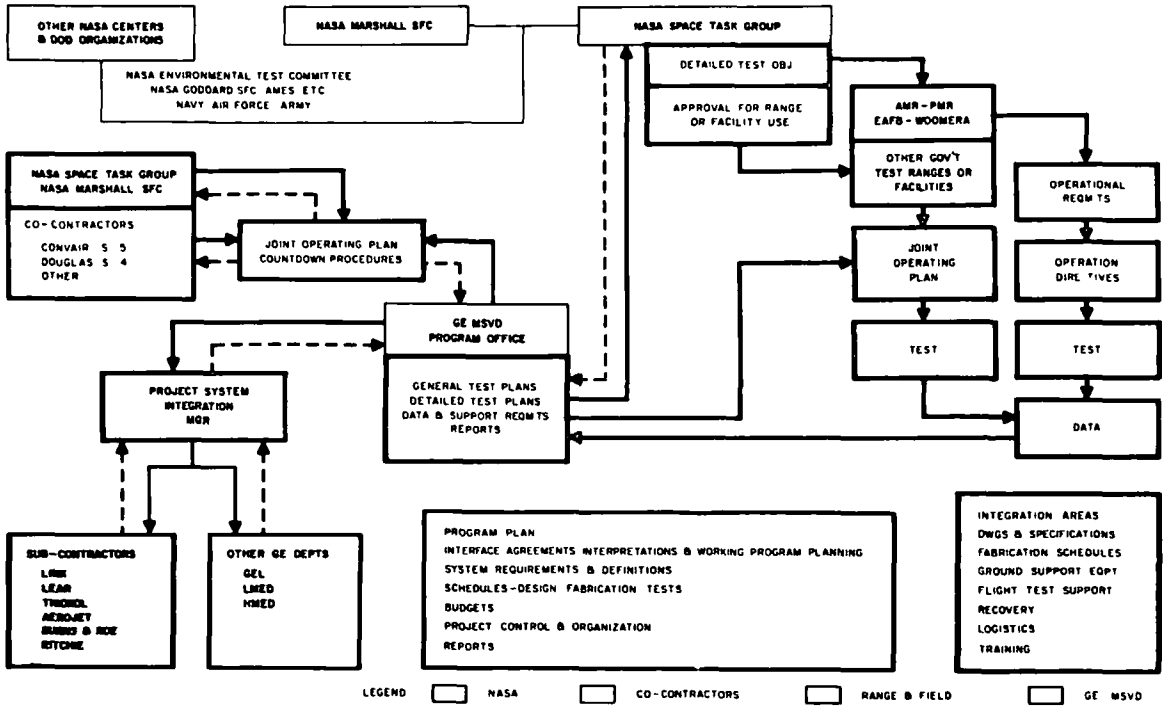

Figure I-3-2. NASA-MSVD-subcontractor system integration

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3. GOVERNMENT RANGES

Integration with various ranges will include the following

(a) Early participation to define each other's responsibility in the program.

(b) Hardware familiarization in the form of lectures and demonstrations.

(c) A Joint Operating Plan will be prepared for various programs including development test and flight test.

(d) Development Test Programs such as Drop Tests, Set-out Tests, and Abort Tests.

(e) Flight Test Program plans, procedures, analysis, and reports.

(f) Training of the Flight and Ground Crews including procedures, hardware, equipment and instructors.

(g) Vehicle pre-flight preparation and check-out.

(h) Field check-out equipment for hangar, blockhouse, and landing sites.

(i) Countdown participation in the field before, during and after flight.

(j) Technical advisers during countdown, flight and landing.

General Electric – Missile and Space Vehicle Department will assign technically competent personnel to assist the launch operation organization (Figure I-3-7), in the following advisory capacities:

Central Control

1. APOLLO System Adviser – to assist the Flight Director
2. Maintenance Adviser – to assist the Space Craft system monitor
3. Trajectory Adviser – to assist in monitoring trajectories and advising on changes where required

Launch Control (Block House)

1. Launch Control Adviser – to assist the Launch Director and advise the Pad Abort Recovery Team

2. Control and Life Support Operator – perform the countdown checkout of Life Support and Control Systems through the Ground Support Equipment

3. Telemetry and Communications Operators (2) – perform the necessary checkout and monitoring of all Space vehicle communications equipment through the Ground Support Equipment

Landing Sites

1. Landing Site Advisers – to assist the responsible NASA directors in landing and/or recovery procedures

For accomplishing integration with various ranges for ground tests the following documents will be prepared:

1. Integrated Test Plan – This is the overall test program described in Section 8.

2. Joint Operating Plan – This describes the responsibilities of the contractor and the various test agencies and documents the operating procedure between participants.

3. Detailed Test Plan – This contains the details of a specific test program and includes specific data requirements, test conditions, equipment and facilities required, etc.

4. Preliminary Test Report – This will provide a quick analysis to determine success of the test. This report may be in the form of a letter, memorandum, or other informal means. It shall contain a statement about objectives achieved. If a malfunction occurred, a statement shall be made about the probable cause of the malfunction, and if possible,

a time history of the events that preceded the malfunction. A general statement shall be made concerning the overall performance of the system and any other statements of interest.

5. Flight Evaluation Report – This report shall contain all information covering the test. This report shall state the objective of the test, a list of all functions that were to be recorded and the telemetry channels utilized. It shall state the results of each objective as well as covering the performance of all subsystems. If a malfunction occurred, or other undesirable characteristics were encountered, the report shall contain a complete analysis of the problems encountered and the proposed solution. This report shall contain all pertinent data.

For accomplishing integration with various ranges for all flight tests the following documents will be prepared.

1. Integrated Test Plan – (see above)
2. Joint Operating Plan – (see above)
3. Data and Support Requirements – This document defines specific data requirements, conditions, equipment and facilities required, etc.
4. Detailed Test Requirements – This document summarizes the detailed test requirements for use by NASA for its documents to AMR or other range.
5. Instrument Calibration Data Report – This document presents calibration information to obtain quantitative data from telemetry.
6. Hangar Check-out Procedures – This determines vehicle operability after transportation and handling.
7. Launch Stand Check-out Procedures – This is used to confirm vehicle operability in test position.

8. Hangar Compatibility Test Procedures – This is used to confirm adequacy of the electrical and mechanical mating.

9. Launch Stand Compatibility Test Procedures – This is used to assure that no RF and/or mechanical interference exists between the APOLLO vehicle, missile and support equipment.

10. Countdown Procedures – This document is an aid in the preparation of combined countdown procedures.

11. Preliminary Test Report – (see above).

12. Flight Evaluation Report – (see above).

13. Analysis Report – This report will summarize and provide an analysis of the entire test program of each major test phase consisting of a series of tests.

3.1 APOLLO PROGRAM PLAN

The APOLLO Program Plan is the primary document used to provide program direction, definition and control to MSVD operating components and subcontractors. It is a working document, prepared and revised regularly by the APOLLO Program Office, to record progressive accomplishment and to update planning based on current program status. The Program Plan also will be sent to the NASA Space Task Group. The Program Plan will include the following:

1. Program Requirements and Objectives

   This section documents the technical requirements and objectives, the delivery schedule and the test schedule as established by NASA

2. Tasks and Schedules

   These sections outline MSVD and subcontractor tasks which will be performed by each operating component such as program management, reliability, engineering, quality control, manufacturing, integrated test, and logistics. The Program Plan, as a working systems integration

document, will document all customer agreements and interpretations as well as all interface agreements with the NASA, co-contractors, AMR, PMR, etc. An internal schedule will be presented for each function, as well as external for all subcontractors which is integrated with the NASA delivery and test schedule given in Section 2.0. Assignment of specific areas of work and responsibility will be made to MSVD operations. Internal budgeting and program control methods to be used on APOLLO will be presented.

3. Data Book

Appendix A to the APOLLO Program Plan is the APOLLO System Data Book. This Data Book will reflect current program status in technical depth. The Data Book will contain:

a. Description of the APOLLO System

b. Design Data such as trajectories, ballistic coefficients, etc.

c. Vehicle descriptions

d. Equipment descriptions

e. GSE descriptions

f. Test equipment descriptions

g. Interface agreements and drawings

h. Specification lists

i. Drawing Lists

3.2 TECHNICAL PROGRAM DIRECTION

The APOLLO Program Manager will be responsible for all technical program direction. This direction will be supplied through the Program Office organization previously mentioned in Figure I-3-1. The mode of transfer of direction, funds, requirements and information between the APOLLO Program Office and the

responsible operation or subcontractor will be conducted utilizing the Program Plan, Program Funding Instructions (PFI's), Program Information Requests/Releases (PIR's), and Specifications.

3.2.1 Program Funding Indurstructions (PFI)

The Program Funding Instruction is used to authorize and fund work. It is issued by the APOLLO Program Manager to the responsible operations, e.g., Engineering, Quality Control, etc. It may also be issued by a responsible operation to another operation or sub-operation. The Program Funding Instruction describes the work requirement, referencing the proper specification, and transfers funds for its accomplishment.

3.2.2 Program Information Requests/Releases (PIR)

The Program Information Request/Release is used for requesting and releasing program and design information between all Operations of the Department. It makes no provision for the transfer of funds. Program Information Requests/Releases requesting or releasing information may be issued by any operation or sub-operation as necessary to meet schedules.

3.2.3 Top System Specifications

Figure I-3-3 shows a tree of those requirements, specifications which will be prepared by the APOLLO Program Office. These specifications are the topmost specifications which contain the NASA requirements and the APOLLO Program Office interpretation of them. (The equipment specifications prepared by the Engineering Operation are given in Section 4.0.) These programs oriented specifications are as follows:

1. APOLLO System Requirements Specification

   This specification will contain the total system requirements as placed on MSVD by NASA. These will include flight performance, GSE performance, operational concepts, reliability, logistics, training, human

factors, maintainability and safety. Test requirements for the total system may be covered by separate documents; however, the test plan will cover flight certification tests, field acceptance tests, launch site tests and development flight tests.

2. External Environment Specifications

   These specifications, one for aerospace equipment and one for ground equipment, will define the environments to be encountered by the system from factory throughout the flight to recovery.

3. Qualification Requirements Specifications

   These specifications, for the system and for both aerospace and ground support subsystems, components and end items, define what must be demonstrated to achieve department qualification. It includes the acceptable stress levels of test for each environment, the sequence of testing, and the methods, such as temperature-time profiles, vibration-sequence-time-profiles, etc., to be used for testing. It includes requirements to demonstrate functional, environmental, and compatibility qualification.

4. Approved Parts List

   The lists of approved parts shall be a tabular listing of parts, i.e., resistors, capacitors, etc., and/or materials which have been established as having basic capability to perform under the use requirements of the APOLLO Program. The parts on this list shall be the sole items used in the design and fabrication of APOLLO hardware. These lists provide the basis for negotiation of non-standard part approval.

3.3 BUDGET CONTROL AND CONTRACT REQUIREMENTS

The Program Control Manager is responsible for control of program costs and with compliance with contract commitments. The following procedures will be employed to accomplish this:

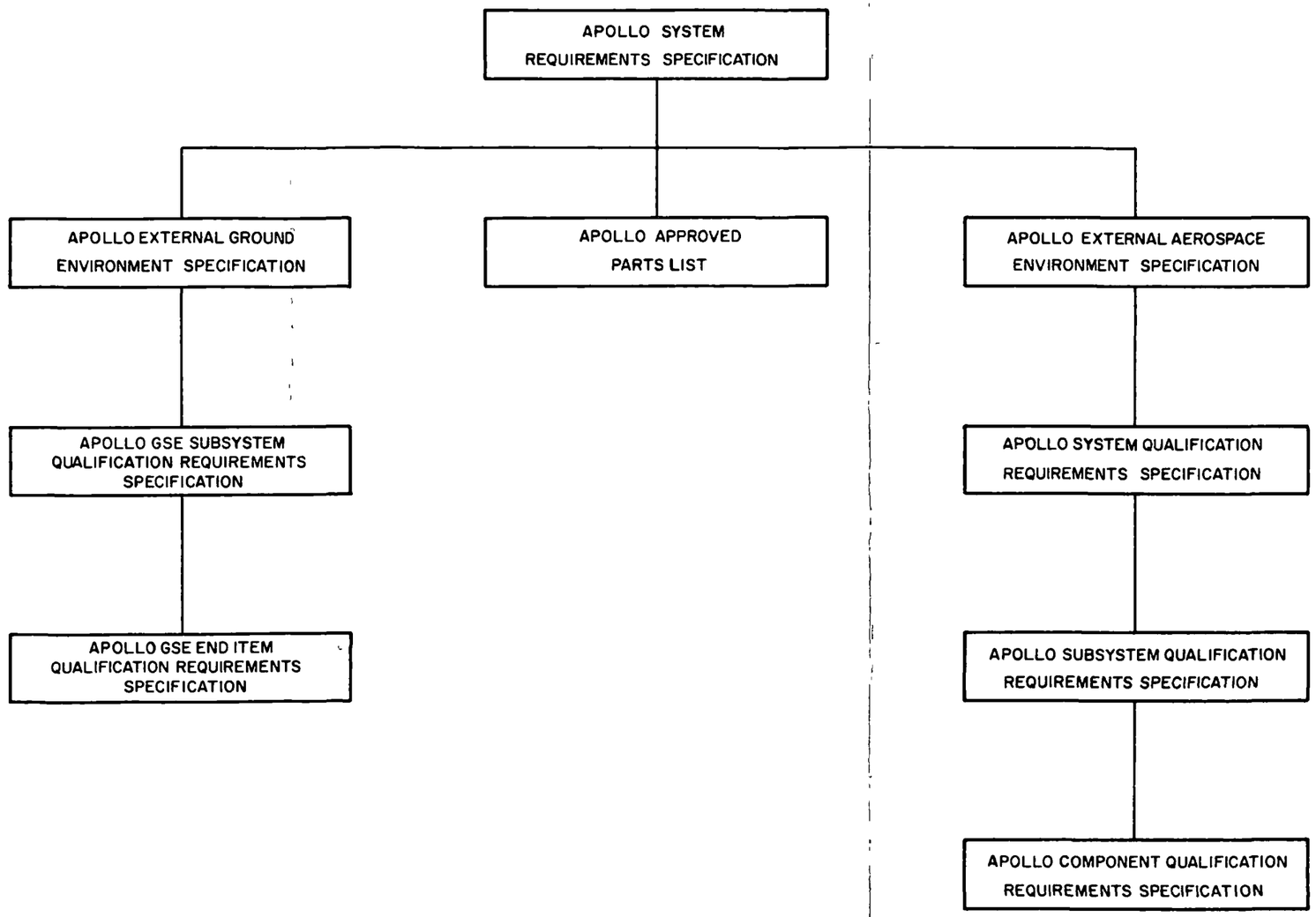

Figure I-3-3. Top system requirement specifications prepared by APOLLO program office

a. Reduction of the program plan into a formalized budget for each Task by calendar quarter through the length of the contract. This budget is based on manhours of professional and supporting personnel needed to accomplish each Task, plus detailed identification of funds allocated for outside purchases. These budgets will change with any change in the program plan.

b. No work is done or charges accepted unless specifically authorized by a Program Funding Instruction. These Program Funding Instructions assume the following uniform format:

1. Objectives – the specific purpose of the PFI.
2. References.
3. Discussion.
4. General Instructions.
5. Requirements – specific listing of the work to be done and reporting of same.
6. Schedule – identified completion dates of work defined in requirements.
7. Funding – direct labor allowed, materials and total dollars authorized.
8. Effectivity – starting and completion dates of work requested.
9. Shop Order Numbers – charge numbers established for collection of costs incurred in performance of work requested.

Funding for each PFI shall be on a calendar quarter basis, with amendments for each additional period authorized by the Manager – APOLLO Program after review of technical accomplishments to date. Expenditures and commitments against each PFI will not exceed the authorization, and work content shall not deviate from the PFI agreement. If

additional funds are requested, the requirement shall be reviewed by the Project Engineer who will authorize the additional expenditures if it is deemed necessary.

c. All requests for development materials and services in the amount of $500 or more must be reviewed and approved by the APOLLO Program Office for technical application, and by Finance for availability of authorized funds.

d. Three days after the close of each calendar week, a Financial Report is submitted to APOLLO Program Management. Information is based on actual charges incurred through the close of the immediate week completed. This report presents actual expenditures and commitments versus the authorized funding for each PFI. It presents:

1. Graphically:
   (a) weekly applied manhour profile
   (b) cumulative applied labor dollars
   (c) cumulative dollar value of materials expended and committed
2. In tabular form:
   (a) weekly and cumulative applied manhours
   (b) weekly and cumulative applied labor dollars
   (c) cumulative dollar value of materials purchases expended and committed

3.4 PROGRESS ANALYSIS

Progress Analysis will be performed under the direction of the APOLLO Program Office as shown in Figure I-3-1. Progress analysis is performed on all MSVD and subcontractor tasks listed in the Program Plan with respect to schedules and Technical accomplishment. This data is then fed into the BEST data processing system described in the next paragraph.

3.5 BUDGET EVALUATION AND SCHEDULING TECHNIQUE (BEST)

The BEST Data Processing System is a modification of PERT which was developed for the Navy by Booz, Allen and Hamilton, as a tool for determining in detail what must be done to accomplish program objectives. It is a proven, advanced method of planning which utilizes statistical theory and computer capability. Plans are developed for the total program down to the level of day-to-day activities of the component development engineer.

BEST analyses, based on bi-weekly computer runs which incorporate current progress or program changes, will indicate in advance potential trouble spots which are most likely to cause serious delays. Proposed corrective action can be made and tested by computer runs to obtain quantitative measures of increased probabilities of meeting deadlines or of expected time savings within budgets.

Figure I-3-6 shows how the BEST system fits in with the total APOLLO program. It permits a continuing evaluation of technical progress versus time versus budgets. As such it is the basis for determining significant trends which permit meaningful day-to-day decisions.

As shown in Figure I-3-4, the APOLLO tasks and schedules from the Program Plan and the PFI budgets are integrated to formulate a series of BEST networks in visual format. Progress analysis is then accomplished on MSVD and subcontractor performance. This data is placed on data processing cards. The networks and cards are programmed and fed into the MSVD IBM 7090 computer. The print out is in two forms; one is a line column page giving a thumb-nail description of the situation for each specific event, the second is a visual representation of the events tied into networks to give the overall picture at a glance. The detailed planning of the networks is accomplished to result in meaningful data to all levels of management; i.e., milestones to top management and detail events to engineering, reliability, quality control, manufacturing, etc.

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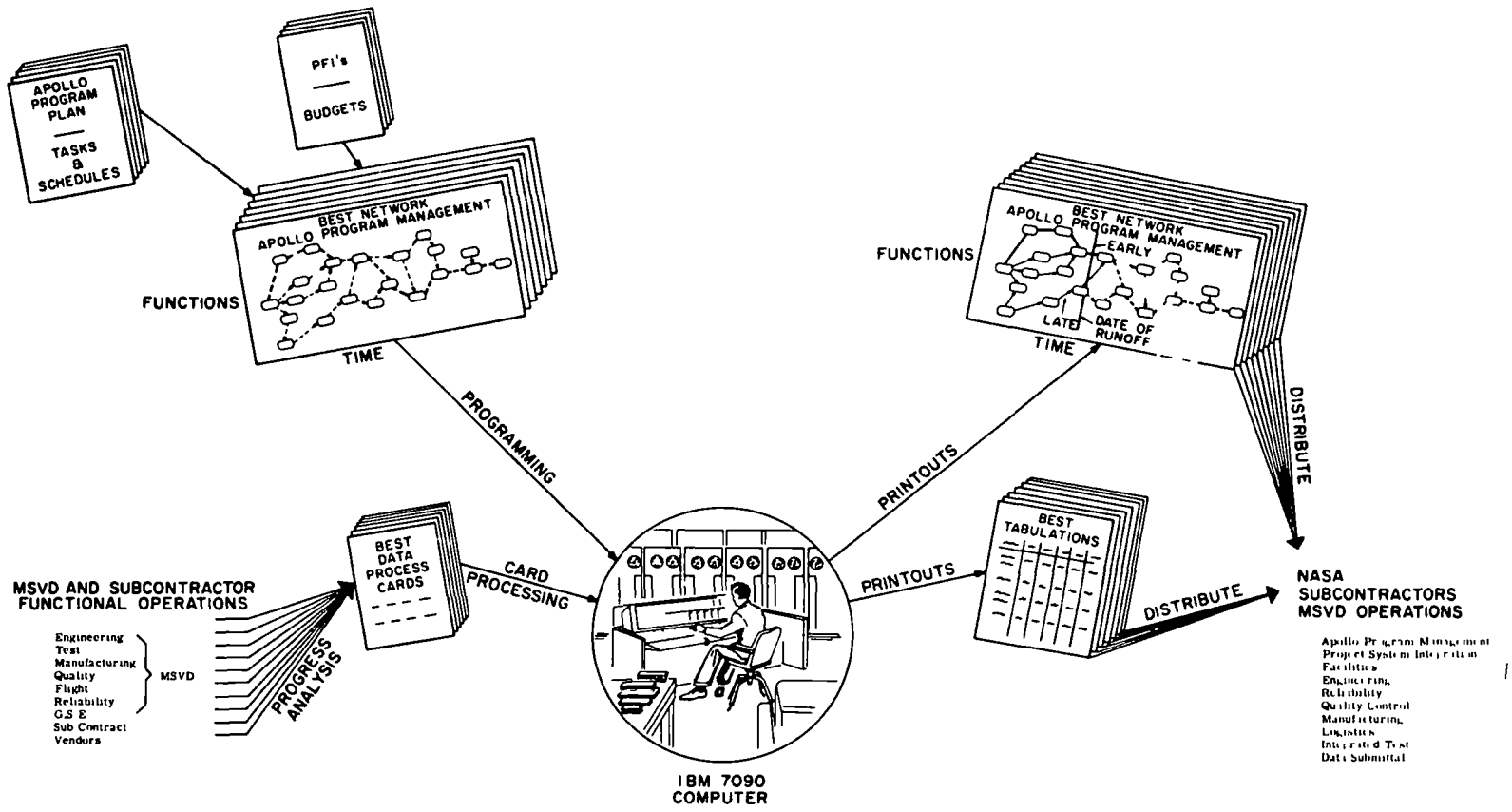

Figure I-3-4. BEST data processing system for APOLLO

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Figure I-3-5 shows a representative sample of the top network from the NIMBUS program covering that program from work statement to final hardware delivery. For APOLLO, such networks will have cost figures and percentages added.

The foundation of the BEST technique is the preparation of a series of flow chart networks which establish program milestones or events which must be accomplished to complete the program. An event is defined as a distinguishable, unambiguous point in time that coincides with the beginning and/or end of a specific task or activity of the R&D process. Arrows connecting events are called activities and represent the work necessary to achieve the event. Activities cannot be initiated according to an existing plan until the immediately preceding event has been accomplished.

Time and cost estimations for completing an activity are shown on the interconnecting arrows and include not one but three time estimates: the pessimistic time, the optimistic time, and the most likely time. From these three time estimates, a probability distribution of a time expected to perform the activity can be constructed. It is then possible to calculate a statistical expected time for the performance of each event and a measure of a potential variability.

With networks established and time estimates available, an analysis reveals the sequence of events, or critical path, which limits program completion. The probability of conforming to this or any other schedule can be calculated. In addition to the critical path, which represents the expected time for completion of the program, the complete matrix defines the total work required to complete the program and, equally as important, the timing and relationship of each individual task relative to any other task. It also focuses attention where decisions are required for risks, and trade-offs in time, costs and manpower.

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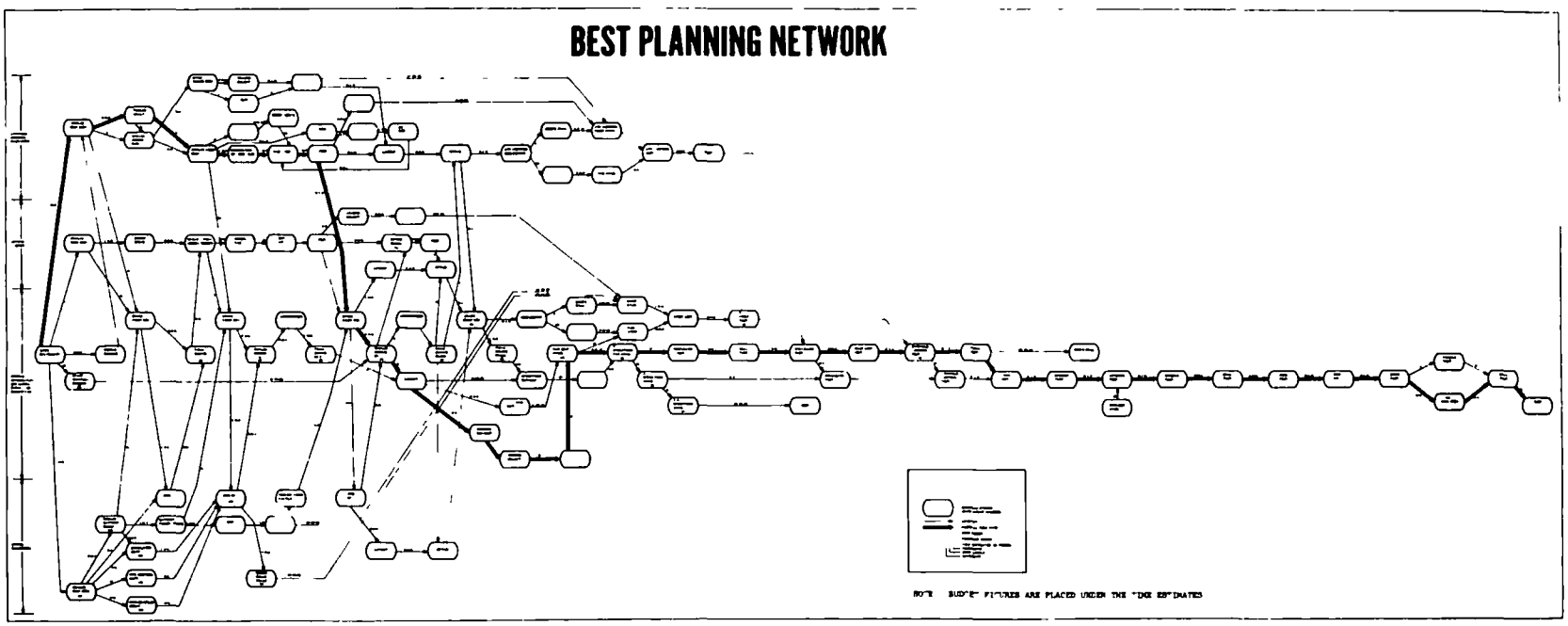

Figure I-3-5. BEST type network as used on Nimbus program

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3.6 DESIGN CHANGE CONTROL

Under the direction of the Design Change Control Office, a Design Change Board will be formed for the APOLLO program, consisting of a cross-section of department personnel (engineering, manufacturing, quality control, test, technical requirements, and projects) and other operations deemed necessary to assure the timely and orderly incorporation of design changes into the manufacturing cycle or test. The chairman of this board will be assigned to the Design Change Control Office of the Projects Operation and will be the personal representative of the Program Manager on the Design Change Board.

The Design Change Board will review all proposed drawing and specification changes to assure:

- Integration of the change among all MSVD effected operations
- A plan for the introduction of the change, and a disposition of any existing material
- That, prior to approval, the change is in accordance with the Program Plan, is timely and that the effects on cost have been considered.

The Design Change Control Office will maintain a center of information on the status of all changes. In particular, records concerning models affected, introduction points, disposition of existing material and all changes approved in a given change package will be maintained.

3.7 PROGRAM REPORTS

Figure I-3-6 shows the major APOLLO program progress data flow starting with NASA requirements and continuing with the Program Plan, specifications, the BEST data processing technique, reports, drawings and evaluations through to the APOLLO Program Evaluation Report. Notice that the data flow system is close-looped to the APOLLO Program Plan with its appended Data Book so that current status is always reflected in the APOLLO Program Plan.

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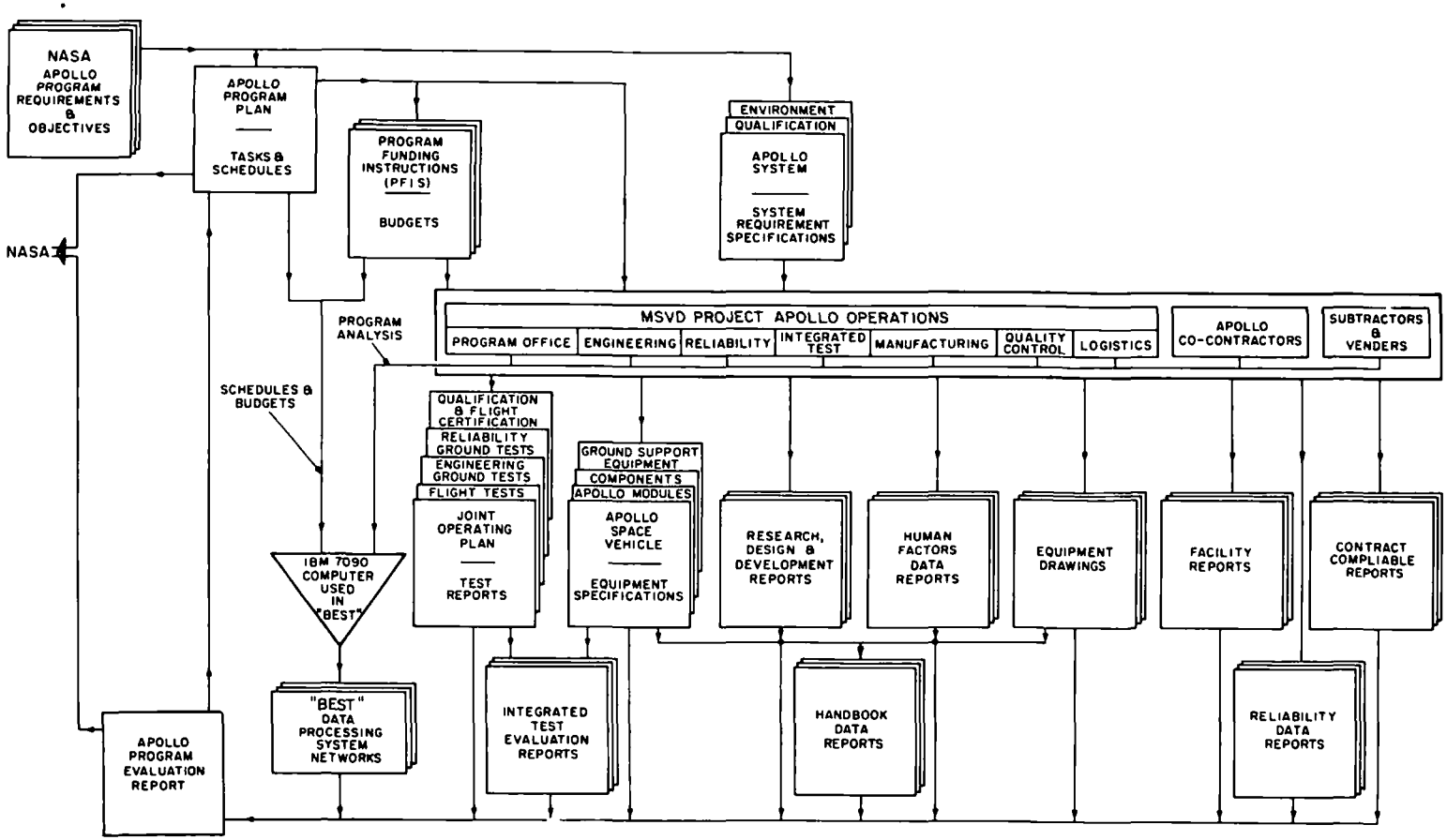

Figure I-3-6. APOLLO program data flow

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The APOLLO Program Office will be responsible for the preparation and distribution to NASA of the following reports which together with the Program Plan, drawings, specifications, and BEST networks will enable NASA to be informed, in technical depth, of the progress and status of the APOLLO program.

3.7.1 Apollo Program Evaluation Report

The APOLLO Program Evaluation Report as shown in Figure I-3-6 will be issued monthly. This report will evaluate total program progress in technical depth which has been accomplished during the reporting period. As shown in Figure I-3-4, this report ties in all performing activities both MSVD, APOLLO contractors and subcontractors. It employs the Program Plan Tasks as a basis of reference and the BEST system to evaluate performance against time and dollars. The basis for evaluating the technical depth of the progress from all other data sources available on the program such as design and development progress reports, system parametric analysis, stage releases, drawings, specifications, test results and reliability progress reports An appendix to the report will contain listings of all drawings, specifications and formal reports issued-to-date This report will be employed to keep the Data Book of the APOLLO Program Plan current.

3.7.2 Reliability Data Report

The Reliability Data Report will be issued early in the program and updated bimonthly. The initial report will establish APOLLO criteria for quantitative requirements and procedures for attaining reliability throughout the program in areas of reliability design prediction and analysis, testing, parts program, failure reporting, manufacturing and quality controls, product improvement and mathematical and statistical methods. The revisions will cover accomplishments in these areas and present reliability status of:

a. Figure of Merit Analysis of the design

b. Design Reviews

c. Test results as a measure of reliability estimates

d. Qualification status

e. Predicted reliability under operational conditions

f. Significant solved reliability problems

g. Failure analysis status

h. Parts program status

i. Vendor reliability status

3.7.3 Research, Design and Development Reports

During the research, design and development phases various reports will be issued covering investigations, analysis, computer programs, parametric determinations, experiments, etc. which are accomplished in developing the APOLLO system. The more significant ones will be distributed to NASA; however, all of them will be referenced in the APOLLO Program Evaluation Report described in Section 3.7.1.

3.7.4 Human Factors Data Reports

Human Factors Data Reports will be submitted during the equipment design and development phases. This data will include:

1. Qualitative and quantitative interrelationships between the system hardware and the people who will operate, handle, maintain and repair the equipment.

2. Task analysis and functional diagrams to illustrate work flow, sequence and nature of work, estimated duration and sequence of functions, and types of individuals required to perform the tasks.

3. Human engineering design criteria which will be factored into design and development. This criteria will be related to human capabilities, control-display relationships, accessibility, lighting, color coding and work environments.

4. Description of necessary training equipment including a functional description and substantiation of each item and the purpose of the item in support of system training of operator and maintenance personnel.

3.7.5 Facilities Report

A Facilities Report will be issued early in the program and updated bimonthly. It will cover the following:

1. Facilities available and required by time schedule for MSVD research, design, development, manufacture and test of APOLLO equipment.
2. Facilities available and required by time schedule for APOLLO co-contractor and MSVD subcontractor research, design, development, manufacture and test of APOLLO equipment.
3. NASA, government and outside commercial facilities to be employed on APOLLO.
4. Government Furnished Equipment (GFE) and Contractor Furnished Equipment (CFE) necessary for test, operation and maintenance of the APOLLO system.
5. Installation facilities required in employing the APOLLO system. These data will be sufficiently detailed for architect-engineering development of such installation facilities required for each APOLLO operational site. This data will include plot and road plans, estimated total number of personnel, facility functional flow charts, utility requirements, safety considerations, open storage and buildings.

3.7.6 Handbook Data Reports

Handbook Data Reports will be submitted during the equipment design and development phases. This data will be used to prepare operating, handling, and maintenance tasks required to support the APOLLO system from factory to launch site and throughout the test and operational flights to recovery of the space craft.

Handbook data will also be prepared for training, field maintenance and field repair. This data will be integrated with NASA, APOLLO co-contractors and MSVD sub-contractors for the preparation of APOLLO System Handbooks to cover all aspects of handling, operating, maintaining, repairing and training on the APOLLO system.

3.7.7 Integrated Test Reports

The various Integrated Test Reports necessary for both ground and flight tests are described in Section 3.0.

3.7.8 Contract Compliance Reports

Various Contract Compliance Reports will be issued as required by NASA to evaluate MSVD performance on the APOLLO Contract. Such reports will include:

a. Fiscal Expenditure Reports and Graphs

b. Geographic Dispersion of Program Expenditures

c. Material Expenditures

d. Monthly Financial Forecast

e. Cost Analysis

f. Manpower Hours and Rates

g. Distribution of Straight Time to Overtime

h. Delivery Status Chart – Vehicles, GSE and Spare Parts

i. Monthly Delivery Forecast

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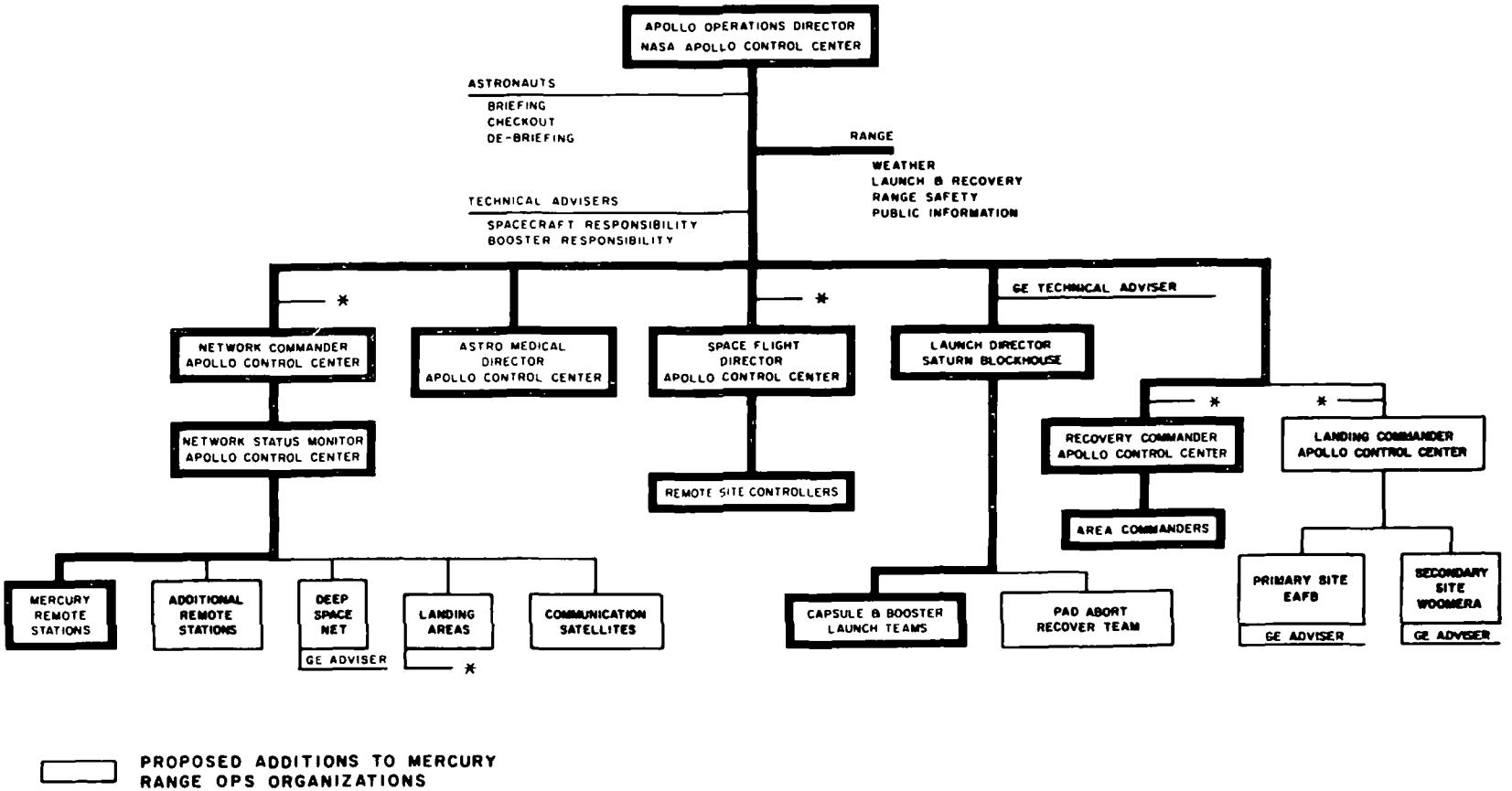

Figure I-3-7. APOLLO launch operation organization

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4.0 Engineering Plan

The technical discussion for the basic design of the APOLLO Space Vehicle, the modules, subsystems and components are presented in the other volumes of this proposal.

The engineering tests to be performed are presented in Section 8.0 of the Program Plan.

The balance of this section defines engineering plans and procedures for the APOLLO design.

The design of the APOLLO Space Vehicle and associated Ground Support Equipment shall be performed in accordance with the overall system requirements established by NASA. Design studies will be performed to determine system feasibility and to verify design requirements. System, subsystem, and component design specifications shall be prepared for the purpose of defining design requirements. Where possible, maximum use of proven design concepts and non-critical materials shall be incorporated in all levels of design activity. In areas where substantial advances in the state-of-the-art will be required to satisfy design requirements, primary emphasis will be placed on reliability.

4.1 DESIGN STAGE RELEASES

To permit concurrent design efforts to proceed simultaneously, a system of Stage Releases defining various phases of design shall be implemented as follows:

4.1.1 Stage 1 Release

The Stage 1 Release is a preliminary design release used to disseminate information between design groups so that simultaneous design can be

accomplished between interrelated equipments. The Stage 1 design definition shall include.

a. Gross requirements for total space, weight, heat output, and power required

b. Identification of components in the form of preliminary parts lists

c. Block diagrams indicating functions and interrelations of components

d. Vehicle configuration including approximate external dimensions, weight, and center of gravity

e. The maximum size of each component required, the sizing shall include necessary connectors, plugs, etc.

f. Maximum weight of each component

g. Identification of the component face which is to be mounted on the structure and definition of mounting holes or fastenings, if available

h. Preliminary description of external component environmental orientations and location limitations

i. Maximum component power requirements and thermal dissipation

j. Estimated power and thermal dissipation duty cycle

k. Initial reliability analysis

4.1.2 Stage 2 Release

The Stage 2 Release is a preliminary design release used to build experimental parts and breadboards for the APOLLO engineering design tests. It will establish further refinements of the APOLLO Stage 1 design information and provide additional design details including:

a. A second iteration of total size, weight, heat output and power

b. Detailed subsystem block diagrams indicating component functions and interrelations and definition of all component performance interfaces

c. Preliminary component packaging arrangement

d. Preliminary requirements for power, switching and monitoring supplied by Ground Support Equipment

e. The size of each component, specified to a dimension tolerance of ± 0.25 inches

f. The weight of each component within a tolerance of 10 percent and its center of gravity location

g. Final size, location, number and type of mounting holes or fastenings

h. Number, type, location and size of all connectors to a tolerance of ± 0.25 inches

i. Definition of internal environment limitations for components that cannot operate in conformance with APOLLO environmental requirements

j. Thermal dissipation and power requirements to 20 percent accuracy and estimated duty cycle.

4.1.3 Stage 3 Release

The Stage 3 Release is a development prototype sketch and a preliminary specification used to build and test APOLLO development prototype hardware. Such hardware will be used for ground and flight testing of components and subsystems, and for a ground test of the complete APOLLO system. The release will establish all component, equipment group, and subsystem

interface data and requirements in final form. All electrical and mechanical interfaces between operations and/or associated APOLLO contractors will be defined. All special requirements such as calibration of subsystems and subgroups of components in a subsystem will be noted. Stage 3 definitions shall include the following:

a. Final confirmation of all special requirements such as accessibility, handling, safety provisions, preferred mounting orientation and environmental limitations not meeting environmental requirements

b. Interconnecting diagram of all subsystem components including terminal boards, shielding requirements, and connectors

c. Definition of requirements for power, switching and monitoring supplied by Ground Support Equipment

d. Definition of subsystem performance and the performance interfaces between components with expected tolerances

e. Final component outline sketch, with dimensions to manufacturing tolerances including connectors, plugs, and all protuberances, mounting hole locations and sizes

f. Second iteration of component weight and center of gravity location

g. Identification of connectors according to AN Number or manufacturer's number

h. Final definition of heat outputs and power requirements to ± 5 percent.

4.1.4 Stage 4 Release

The Stage 4 Release is the APOLLO production prototype release. It consists of final parts lists, component and assembly drawings, and specifications for

components, subsystems, modules and the space vehicle. The design information contained in this release will embody results of all testing during stages 1, 2, and 3. Stage 4 hardware will be used for qualification testing of components, subsystems, modules and the complete space vehicle.

4.1.5 Stage 5 Release

The Stage 5 Release is the APOLLO production release consisting of Stage 4 drawings and specifications updated with test information acquired from Stage 4 hardware tests. Stage 5 hardware will be required to undergo Flight Certification Testing. Only Stage 5 hardware can be employed for manned flights.

4.2 SPECIFICATIONS

Figures I-4-1 and I-4-2 are the specification trees for Aerospace Equipment and Ground Support Equipment. The program oriented specifications above the dotted lines are prepared by the APOLLO Program Office. The system, subsystem, component, and other specifications below the dotted line will be prepared by the Engineering Operation.

To assure that thorough integration of specifications has been accomplished, a Review Check List will be utilized to indicate concurrence of designated representatives within the affected operations. The finalized specification will be reviewed and approved by the APOLLO Program Office prior to issue.

The following specifications will be used as general format guide lines in the preparation of APOLLO specifications:

MIL-W-9411	Weapon System, Aeronautical, General Specification For
MIL-S-8169	Specifications, Detail-Guided Missile, Preparation of
MIL-D-9310	Data for Guided Missile Weapon System

MIL-D-9412	Data for Ground Support of Weapon Systems, Support Systems, Subsystems and Equipment
MIL-S-6644	Specification Equipment, Contractor Prepared, Instructions for the Preparation of
MIL-S-8048	Specifications, Aeronautical Weapon Systems, Preparation of

The equipment specifications will follow the format and content as specified in the above government specifications. The other specifications will be as follows·

4.2.1 APOLLO System Design Specification

This specification details system parameters, subsystem requirements and establishes the mechanical and electrical interfaces between them in order to meet the System Requirements Specification. This specification shall contain Acceptance, Flight Certification, and Qualification Testing Requirements as well as the following types of design information:

a. Performance capabilities
b. Facilities
c. Human Factors
d. Reliability
e. Maintainability
f. Operability
g. Logistics
h. Training
i. Safety
j. System Hardware

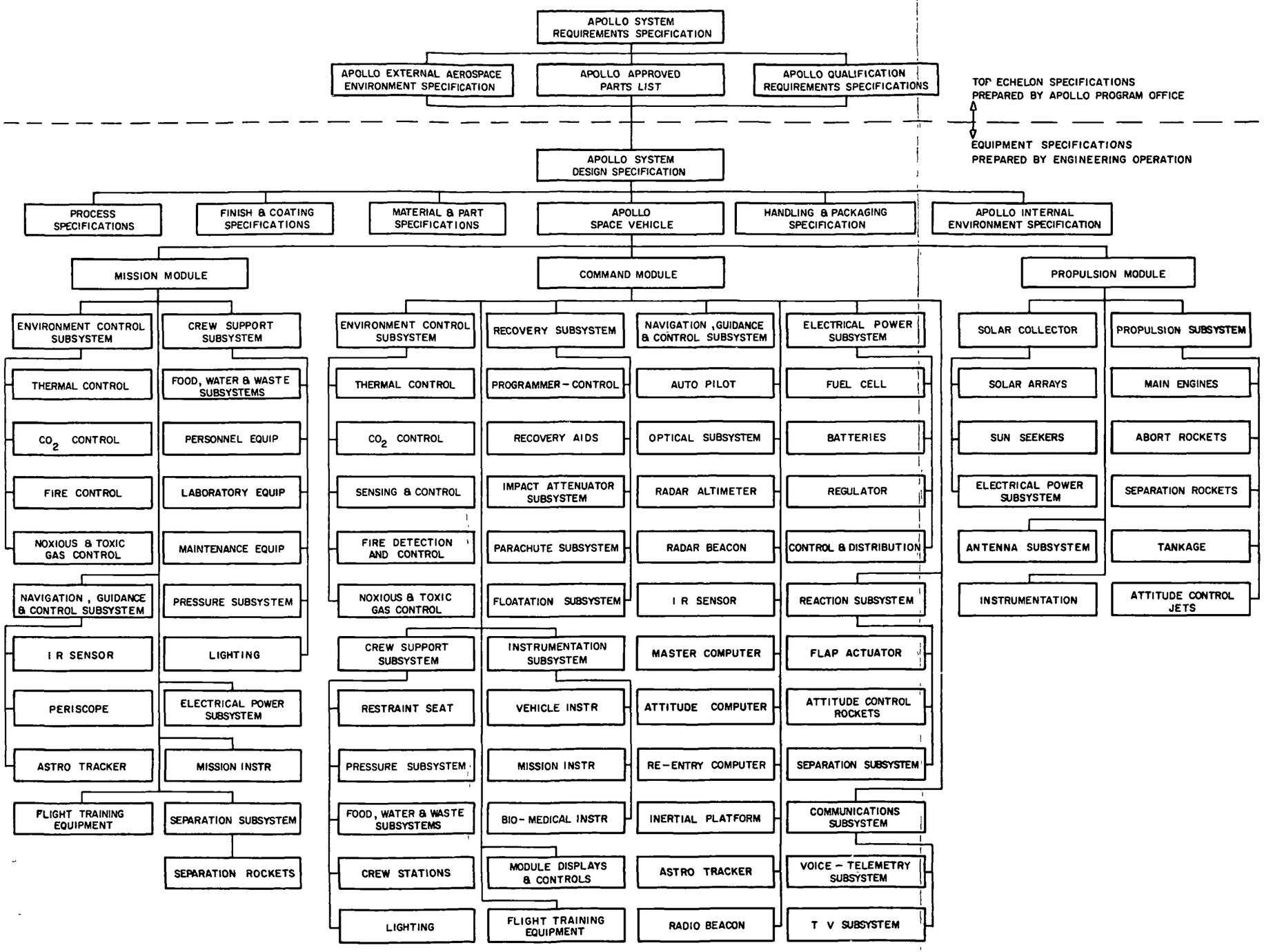
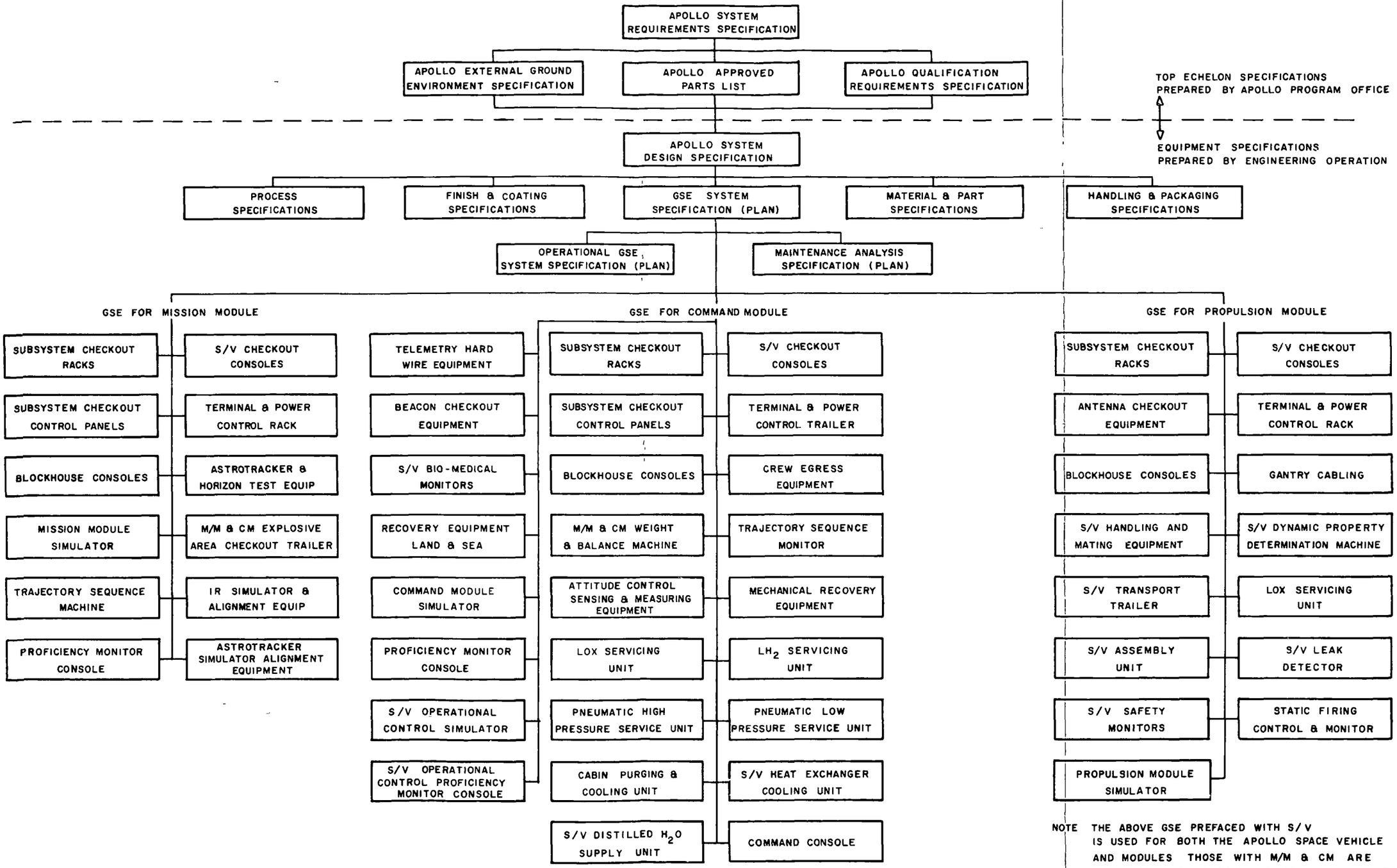


Figure I-4-1. Space Vehicle equipment specification tree



NOTE THE ABOVE GSE PREFACED WITH S/V IS USED FOR BOTH THE APOLLO SPACE VEHICLE AND MODULES THOSE WITH M/M & CM ARE USED FOR BOTH MISSION & COMMAND MODULES

Figure I-4-2. GSE equipment specification tree

4.2.2 Internal Environment Specification

This specification delineates the environmental condition internal to the APOLLO Space Vehicle for internally mounted equipment. The environments from factory through end use are specified.

4.2.3 Process Specifications

Process specifications containing detailed requirements for the various processes and sundry materials used in the APOLLO fabrication cycle will be prepared to define the methods for assembly, joining, finishing, etc., of parts, materials, assemblies and subassemblies. These specifications will also contain the quality assurance provisions for the acceptance of the completed process at its significant stages. Step-by-Step Standing Instructions based upon these specifications are used to implement these requirements.

4.2.4 Handling and Packaging Specifications

This specification shall specify the details of special handling, to be performed and packaging test data to be recorded for packaging of hardware and spare parts.

4.2.5 Parts and Materials Specification

These specifications define part performance and material characteristics, reliability provisions, and quality assurance provisions. They shall be prepared as supporting documents to the System Design Specification.

4.2.6 GSE System Specification

This specification consists of two parts:

a. Operational Ground Support Equipment System Specifications
This is a chronological sequence of the functional support events which must occur from delivery of the major operational element

of the system at the factory through the complete operational use of the system.

b. Maintenance Analysis Specification

This consists of an analysis of each functional element of the system, their functional subsystems, or equipment and the operational ground support equipment items to define functionally the maintenance requirements.

During development, the equipment specifications will be prepared in two parts; the equipment specification and the equipment qualification specification. The purpose of keeping the qualification test portion as a separate document is to integrate it into the qualification program. The Stage 5 Release will combine the two portions of the equipment specification into one document.

4.3 DESIGN PROCEDURES

The basic engineering work plan will be established through (BEST) planning techniques described in Section 3.0. At regular intervals, Engineering will report to the Program Office the events that have been completed and any changes in design planning which will affect existing (BEST) networks. The information thus obtained will be used to complete current program status and determine schedule revisions.

Schedules for the overall design activity will be issued from the APOLLO Program Office. Based on this information, detail working schedules will be prepared and executed within the Engineering Operation.

Using the APOLLO System Requirements Specification, the system design groups will develop subsystem design specifications defining the basic functional requirements of each component, including weight and reliability apportionments. Analyses will then be performed to explore basic design

approaches. Experimental programs may also be required to evaluate the adequacy of various parts, materials, and designs. The various design approaches will be compared on the basis of complexity and probable reliability, power requirements, accuracy, and weight. During the analysis phase there will be a continual information feedback from the component designer to the subsystems designer in order that the subsystems design may be optimized. Having made a preliminary decision as to the basic approach, the component designer will prepare and issue a preliminary component specification, expanding the component requirements as received from the subsystems design group.

A preliminary Standard Parts List will be prepared. The purpose of this list is to identify a limited number of highly reliable parts which then will be extensively life-tested under vacuum and thermal environments. The component designer, in preparing his initial schematic, will utilize this parts list to the fullest extent possible on all circuit designs. In the event a part not included on the Standard Parts List is required, he will, in consultation with the Design Standards Group, select the additional parts required for his application. These additional parts will then be added to the Standard Parts List and subjected to life testing. The component designer, using parts failure rates provided by the Design Standards Group, will estimate the reliability of his design using techniques outlined in the Department Reliability Manual.

Upon completion of the design reliability estimate, a Design Review will be conducted. The Design Review Board will consist of specialists within and outside of the Department. The Review Board will study the proposed design with emphasis on performance, reliability, and weight requirements. Particular attention will be given to reliability in reviewing the designer's analysis, his application of parts, his use of redundancy, and consideration of other

design approaches. At this point, a Stage 1 Design Release will be issued. This release will be used by the structural engineering group in making preliminary configuration layouts, and along with the schematic, will be reviewed by Systems Engineering to check conformity, weight, reliability, and power requirements.

Next, the design will be breadboarded, incorporating the recommendations of the Design Review Board when practicable. The circuit will be experimentally evaluated and optimized; the requirement for new parts, arising from the breadboard work, will be integrated with the Design Standards Group as outlined above. During breadboard testing, packaging design will also be initiated.

A Standards Packaging Group will establish a preliminary set of standards and criteria for the packaging of electronic parts. The purpose of these packaging specifications is to insure the highest reliability in the packaging design. Particular emphasis will be given to the thermal aspects of packaging. All heat transfer paths must be adequate, and the number of thermal interfaces must be minimized. In parallel with breadboard testing and packaging design, component refinements resulting from iterations of the system and subsystems designs will be made.

When a satisfactory packaging design has been determined, a Stage 2 Design Release will be issued. This release will be used by the Structural Engineering Group in preparing the Stage 2 configuration layouts. The complete configuration, with all component thermal dissipations identified, will then be analyzed by the heat transfer group and reviewed by Systems Engineering for compatibility with weight, power and reliability requirements.

The APOLLO approved Parts List will be under continual revision as results of the extensive parts test program become available. Similarly, the packaging specifications will be refined as a result of analytical and experimental programs.

Throughout the course of the component design, the design engineer will keep his schematic and packaging drawings in conformance with these standards.

Shortly after Stage 2 Release the second design review will be held. The Design Review Board will again review the electrical and mechanical design, the reliability analysis, and the results of breadboard tests and make appropriate recommendations.

When the basic performance tests on the breadboards have been completed, the design engineer will initiate work to determine voltage profiles of the design. This is a technique for increasing reliability by establishing a drift tolerant circuit. The component designer will obtain from the Design Standards Group the drift tolerances for each electronic part under three-year space environment. Using these tolerances, the value of each individual part (ohms for a resistor, etc.) will be determined; first at the high limit, with supply voltages varied above and below nominal values until the circuit performance fails to meet specifications, and then at the low limit with the supply voltage varied about nominal until the circuit fails to meet specification. The voltage profile will indicate those parts which have the most significant effect on circuit performance.

At the conclusion of breadboard testing and packaging design, a Stage 3 Release will be issued. At this point, a third design review will be held. The component will be reviewed for proper application of preferred parts and use of redundancy techniques. The reliability analysis, heat transfer analysis, packaging design, and the results of all breadboard testing, voltage profile tests, "worst case" computer studies and test plans for the engineering model will also be reviewed.

The Stage 3 releases will be used by the Structural Engineering Group for preparation of Stage 3 configuration layouts and thermal analysis; Systems

Engineering will review the Stage 3 release for design compatibility, weight, power, reliability and functional requirements. The drawings, specifications and test plans for the typical component will then be released for equipment procurement and environmental test planning. During the fabrication period, work will continue on voltage profiles and other breadboard tests.

Engineering models will be bench tested to check performance. One unit will be subjected to a temperature survey test. The purpose of this test is to verify the adequacy of the packaging design. The test will determine:

a. The various part surface temperatures within the component

b. The rate of heat transfer across the component mounting surface and the rate of radiated heat transferred under simulated thermal and vacuum environments

The results of the tests will demonstrate the adequacy of the component mounting techniques and also the adequacy of the component packaging design.

The component design engineer will modify his design as required by the results of exploratory environmental tests, and subsequent subsystems and systems test. When a final design has been tested satisfactorily, a Stage 4 Design Release will be issued and another Design Review conducted. The Board will review:

a. The final schematics and packaging drawings

b. The results of the component evaluation tests

c. The reliability analysis and the results of voltage profiles and "worst case" computer studies.

With the approval of the Design Review Board, orders will be placed for production prototype equipment to these Stage 4 Releases.

Upon receipt of the production prototype equipment, it will be subjected to the acceptance test specified in the component specification. After satisfactorily completing acceptance test, each component will be subjected to formal test as outlined in the systems specification and as identified in detail in the component specification.

In the event a component fails to meet evaluation test requirements, a failure analysis will be conducted, appropriate modifications made in design, and the tests repeated. Upon successful completion of the tests, results will be presented to the Integrated Test Board for review and "buy-off". An interim design buy-off may be obtained before the completion of extended life test to permit advance order of prime equipment hardware. After "buy-off" the component specification and complete drawings will be issued as a Stage 5 Design Release.

4.4 RELIABILITY SUPPORT TASKS

4.4.1 Figure of Merit Analysis

The Figure of Merit Analysis is a reliability technique employed throughout all engineering design stages from the initial concept to the final design freeze, for the purpose of:

a. Providing one of the means for the comparison and evaluation of alternate designs for effective performance in a given function or mission

b. Serving as an indication of the potential reliability of the design

c. Evaluating progressive design improvements to achieve high reliability.

Each component, subsystem and system engineer will perform progressive Figure of Merit Analyses of the APOLLO design for which he is responsible.

Reports will be prepared of the analysis with completed Part Usage and Application Data Forms. The analysis will be performed in accordance with handbook TRA-873-74, "Reliability Analysis Data for Systems and Component Design Engineers", MSVD, General Electric Company, 8 April 1960.

The Figure of Merit Analysis described in the referenced handbooks is a technique to select one of two or more designs with respect to reliability based upon a Reliability Figure of Merit (RFM) which indicates areas critical in high failure rate potential. The RFM is a value derived through analytical methods which expresses the probability that the component or system under design will give a performance without failure for the required length of time and in the manner and environments in which it is to operate. This value is based on the scale of zero to 1.00 as maximum.

5.0 Reliability Plans

The General Electric Company has long stressed the inclusion of high reliability objectives as a basic part of all weapon system and space vehicle development programs. In keeping with this philosophy, an effective reliability operation has been established to coordinate and integrate the numerous reliability activities. The program proposed for APOLLO represents an enlargement and extension of the reliability program which has proved its value on the Mark 2 and Mark 3 re-entry Vehicle Programs, the Communication Satellite, and other vital defense projects.

The reliability program for APOLLO will be a prime aspect of the overall effort and will be directed to assure the accomplishment of the system operational objectives. All elements of the Design, Purchasing, Manufacturing, and Testing Operations will be geared to a continuous, conscious recognition and evaluation of the reliability influence of their activities. Directed by the APOLLO Program Office, with the support of a strong reliability organization particular emphasis will be placed upon·

a. Assigning reliability objectives to the equipment development.

b Controlled part usage, assuring the employment of only those parts which have known reliability capabilities

c Quantitative evaluation by design engineers of their progress towards achieving their reliability objectives

d. Regularly scheduled Design Reviews utilizing specialists from the Missile and Space Vehicle Department, other General Electric Company facilities, and expert consultants from universities and industry with special attention to the reliability significance of all design considerations.

e. A comprehensive testing, failure analysis, and measurement program with a closed loop into the design and manufacturing operations to provide the substantiation of the design approaches and manufacturing techniques.

f. An education program that will develop a recognition by all activities of the importance and significance of their contribution to the overall reliability effort.

g. A rigid procedure for the review and control of all activities influencing reliability.

5.1 GENERAL RELIABILITY PROGRAM

The presently functioning MSVD reliability organization will be employed on APOLLO. The proposed program is a directed extension of the General Electric Company Missile and Space Vehicle Department reliability activities which have proven their value on numerous ballistic missile and space vehicle contracts. The APOLLO reliability program elements are as follows

1. Reliability Design
   a. Reliability design analysis and apportionment
   b. Operational environmental studies
   c. Component part program
   d. Basic design practices
   e. Reliability education
   f. Design review
2. Reliability Measurement
   a. Specification review
   b. Qualification test program
      (1) Integrated test program boards
      (2) Equipment qualification life testing
   c. Operating data accumulation

d. Failure reporting and analysis

3. Reliability Maintenance
   a. Quality control co-ordination
      (1) Manufacturing
      (2) Ultra-clean assembly areas
      (3) Lot control
      (4) Process Control
      (5) Operability Assurance
   b. Vendor reliability program
   c. Design change control

4. Reliability Analysis
   a. Statistical test planning
   b. Statistical test evaluation
   c. Special analytical studies
   d. Mechanized reliability program
   e. Reliability Prediction

Figure I-5-1 shows how these reliability functions start with preliminary design and follow the hardware through all development phases until production is completed.

5.2 RELIABILITY DESIGN

The objectives of Reliability Design will be to assure the formulation of a basic design having the required reliability potential by accomplishing the following activities.

5.2.1 Reliability Design Analysis and Apportionment

A. Human Reliability Factors will be investigated in the following studies:
   1. Studies to determine reliability of the human operator to:

a) Monitor and switch

b) Compute and actuate in the man-machine servo-loop

c) Maintain, repair and replace in required time interval.

2. Studies to establish probability of acceptable response to various situations and stimuli under a variety and combination of natural and induced stresses.

3. Evaluation of mission profile plan and schedule to establish mathematical probability model·

   a) For individuals of crew involved in discrete tasks or operations

   b) For entire crew unit in providing, monitoring, switching, maintaining, repairing and replacing functions as would be required.

B. Reliability Design Analysis will be carried out as follows·

1. Continuous analysis by the design engineer using both

   a) Reliability Model of Man-machine subsystem to determine mission success.

   b) Probability of Crew Safety Model to describe the instantaneous return capability due to mission abort.

2. Continuous consultation between the design and systems engineers and the reliability analysis engineers throughout design stages.

3. Review of the reliability design analyses and monitoring of the design effort by R & TR.

The first analysis will begin early in the design cycle, with the reliability apportionment of the subsystems and components for reliability design objectives using the relative complexity of the equipment, the severity of the operational environment, criticality of equipment and past experience as guides. Allowable equipment failure

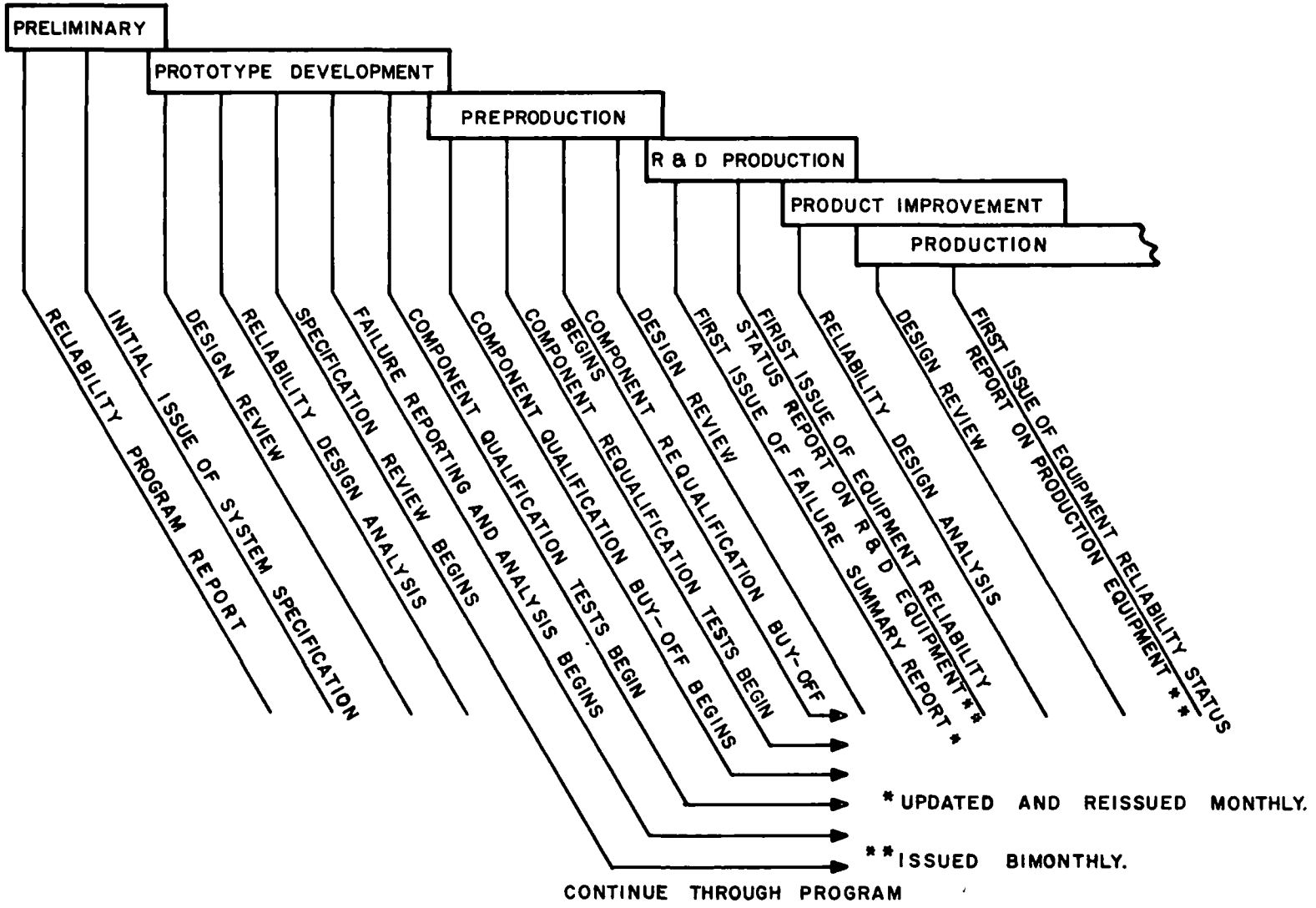


Figure I-5-1. Reliability key events and monitoring points

rates will be established, based on the apportioned reliability values. Forms for methodical analysis of the data will be supplied by the MSVD Handbook "Reliability Analysis Data for System Component Design Engineers," and the "Reliability Design Analysis Manual TIS60SD552."

In order to establish a means of continuously assessing the reliability achievements, the apportioned reliability and failure rate indices will be used for design guidance and evaluation of parts, circuit design, and packaging adequacy.

Based upon this initial apportionment, and utilizing the same techniques, part apportionment will be performed by the cognizant subsystem and component design engineers, who will determine the design reliability of their components using failure rate information. A reliability review will be conducted on components and parts relative to the above mentioned design considerations, in order to determine accomplishment of the assigned reliability objective.

Each responsible component design engineer will conduct figure-of-merit analyses of all design configurations. During the figure-of-merit analysis, a detailed analysis will be performed by the responsible design engineer on each circuit employed in APOLLO. The purpose of this analysis will be to determine the stresses (electrical, environmental, and mechanical) which will be encountered by each component part. Indicated reliabilities resulting from the figure-of-merit analysis will be used to reapportion new goals. This procedure will be repeated at regular intervals throughout the design cycle. All system, subsystem, and component analysis will be reviewed by the Reliability and Technical Requirements Operation for proper application of method, and verification of analytical approach The procedure will have the dual purpose of indicating adequacy of design efforts, and permitting effective management direction of the program.

5.2.2 Operational Environment Studies

There are three distinct environmental phases associated with the APOLLO Program which will be analyzed.

1. Preflight
   a. Transportation and storage
   b. Handling and mating
   c. Preflight checkout
2. Flight
   a. Launch
   b. Earth Orbit
   c. Cislunar midcourse
   d. Circumlunar midcourse
   e. Lunar Orbit and de-orbit
   f. Abort regimes
3. Recovery
   a. Direct re-entry from midcourse
   b. De-orbit
   c. Re-entry and maneuvering
   d. Search and recovery

The preflight phase is well defined, and the types of environments and their levels are readily correlated to the program from established data and requirements obtained from previous programs. Information from such sources as military standards, specifications, handbooks, and similar documents, in conjunction with specific test data obtained from comparable systems and hardware under similar environments will be used.

For the flight and recovery phases information from standard references and handbooks, and specifically, the current continuing inputs from space probes, satellites and manned space flights will be used. The environmental information thus obtained

will be analyzed, evaluated, and compared for compatibility with the specific requirements of the APOLLO program. The de-orbit, re-entry, and recovery phase is essentially defined, based on General Electric MSVD experience with current programs. The evolved criteria will form the basis for the external and internal environmental specifications for the parts, components, subsystems, and system for the program. In addition, a general compilation and evaluation of this information will provide:

1. Guidance for hardware design in the components and system areas.
2. Basic reference in the testing program for parts, components, and systems, particularly with regard to requirements, methods, and facilities. Environmental criteria will be prepared and issued by the Reliability and Technical Requirements Operation. These criteria will detail the environments to be encountered in operational usage, together with test levels containing an adequate safety factor at the part, component, and system levels.

Duty-stress profile data, showing equipment operational requirements as a function of time, will be compiled for utilization in the reliability prediction phase, and as a guide in component part testing.

5.2.3 Component Parts Program

A parts program will be established to assure that only selected and controlled parts of the reliability and longevity required are employed in the project. The program has three-phases, namely, the selection, the evaluation of parts, and the control of parts usage. The planned APOLLO Parts Program is discussed in considerable detail in Appendix A of this section.

1. Selection of Parts. The parts selected for use in the APOLLO will be of the highest quality and reliability attainable based upon prior knowledge of part and vendor capabilities. The parts are to be compiled and presented on an Approved Parts List which will form the

basis for parts used in equipment design. The Approved Parts List will be formally issued monthly and will be maintained as the project design progresses.

2. Evaluation of Parts. All parts selected for APOLLO will be evaluated to determine that they have the necessary longevity and reliability. Wherever possible, data previously accumulated and documented by MSVD, vendors, military agencies, outside test laboratories, and other industrial sources will be utilized. Necessary studies will be undertaken to provide the required data or to supplement partial information previously accumulated.

3. Control of Part Usage. The approved Parts List will be updated to indicate the parts which are suitable and can also be expanded to include qualified vendors for the parts, and part application data. The approved Parts List will constitute a limitation on the parts that may be utilized in the project. Monitoring procedures will be instituted to assure conformance to this requirement, and will provide for review of parts application and usage data in early design stages and the establishment of firm purchasing procedures for final hardware.

   Part purchase specifications and drawings will be prepared and issued. The drawings will contain the necessary screening procedures required to be performed either by a vendor, an outside contracted facility, or by the Quality Control and Test Operation. In addition, incoming inspection procedures to be issued and used by Quality Control and Test will be detailed and, where applicable, acceptable reliability levels will be stipulated with a requirement that they must be demonstrated by the vendor. Design reviews will provide an additional means of assuring that preferred parts are being utilized and that recommended application techniques are being followed.

4. Standards and Application Information. The existing department standards will be applied to the program. New standards will be prepared as required, based upon environmental stresses peculiar to this program.

5. Test Data Interchange. This department will participate in test data interchange programs which are applicable to APOLLO.

6. Failure Reporting. A failure reporting procedure will be instituted for component parts to determine significant failure modes which may be utilized in providing general design improvements.

5.2.4 Basic Design Practices

Information on the following design practices will be employed for increasing equipment reliability by disseminating them to MSVD, subcontractor and vendor personnel.

1. Reduction of equipment complexity.
2. Use of adequate safety margins in design, between the equipment strength and the related stress which it is expected to experience.
3. Proper use of de-rating of parts.
4. Use of design safety factors which take into account equipment storage requirements and the operational degradation factors.
5. Use of tolerant circuitry, which allows for component part variations, as a function of time.
6. Selection of the most suitable parts available.
7. Redundancy through duplication of critical elements and circuitry.
8. Design improvement, through engineering test, analysis, and redesign.

5.2.5 Reliability Education

The Reliability Operation will administer a reliability training program with the following objectives:

1. To acquaint concerned persons with the reliability requirements of APOLLO.
2. To develop an attitude of reliability-consciousness within all concerned persons.
3. To acquaint concerned persons with the latest available reliability tools.

The following groups of personnel will be trained: Design Engineers, Manufacturing and Quality Control Engineers, Production Workers and Inspectors, Purchasing Personnel, Vendors and Sub-contractors, and new employees.

Design engineers will be instructed in the latest principles, methods, and approaches which can be utilized in the design of reliable equipment. This instruction will include:

1. Synopsis of reliability engineering.
2. Workshop seminars on reliability of designs
   a. Discussions of problems being encountered by APOLLO engineers in designing for reliability parameters.
   b. Specific investigation and explanation of tools available in evaluating designs from concept through production stages.
   c. Specific live examples from problem areas being encountered by APOLLO engineers.
3. Motion pictures and use of consultants.

Manufacturing and quality control engineers will be instructed in the latest principles of the maintenance of reliability and failure prevention in manufacturing. This instruction will include.

1. Synopsis of Reliability and QC/Manufacturing Engineering.
2. Workshop seminars on problems being encountered by APOLLO Manufacturing and QC Engineers in the reliability area.
3. Motion Pictures and use of consultants.

Purchasing personnel will be instructed through the use of workshop seminars and motion pictures for the following purposes·

1. To explain the meaning of vendor reliability specifications, and what is required of APOLLO vendors.
2. To explain how purchasing can contribute to attaining high reliability.

Vendor and subcontractor personnel will be instructed through the use of seminars and motion pictures for the following purposes·

1. To explain the meaning of the APOLLO Program to the vendor, and how they can contribute to the attainment of high reliability.
2. To explain the meaning of vendor reliability specifications.

Manufacturing workers and inspectors will be instructed through the use of motion pictures and an APOLLO development file for the following purposes

1. To increase reliability by stimulating the individual's interest in his contribution to the over-all program.
2. To provide specific training for the job.

5.2.6 Design Reviews

Design reviews will be conducted on the system, subsystems and component levels. These design reviews will follow the sequence given in Figure I-5-2. System Design Reviews will be held periodically to consider the adequacy of the system to perform reliably in the specified environments. The types of reviews held are as follows with the information which will be available for review at each phase.

1. Preliminary system concept and requirements, environmental requirements, reliability program plans, test plans, critical parts list.
2. Interim drawings releases, reliability apportionment by subsystem and component, preferred parts list, early test information.
3. Final subsystem performance capability, test information (development tests, life tests, in-house tests, acceptance tests), reliability analysis (system, subsystem, component predictions), completion of qualification tests, (performance capabilities, field operation specifications, qualification status, manufacturing and quality control procedures).

The Design Reviews will be conducted in accordance with the Missile and Space Vehicle Department design review procedure. Minutes will be prepared and issued on each System Design Review held.

Component design reviews will be held on each component for use on APOLLO. These design reviews will be scheduled on the basis of stage release dates for the components. A design review will be held at the preliminary design phase, to provide recommendation or verification by specialists. All components will be reviewed prior to final drawing release, to evaluate the design with respect to system requirements, fail-safe elements, and devices used in design, appropriate redundancy, stability of circuit design, boost approaches being used in meeting design requirements, proper selection and application of component parts and materials, adequacy of de-rating factors, environmental stresses, wear-out parts, human-use factors, packaging,

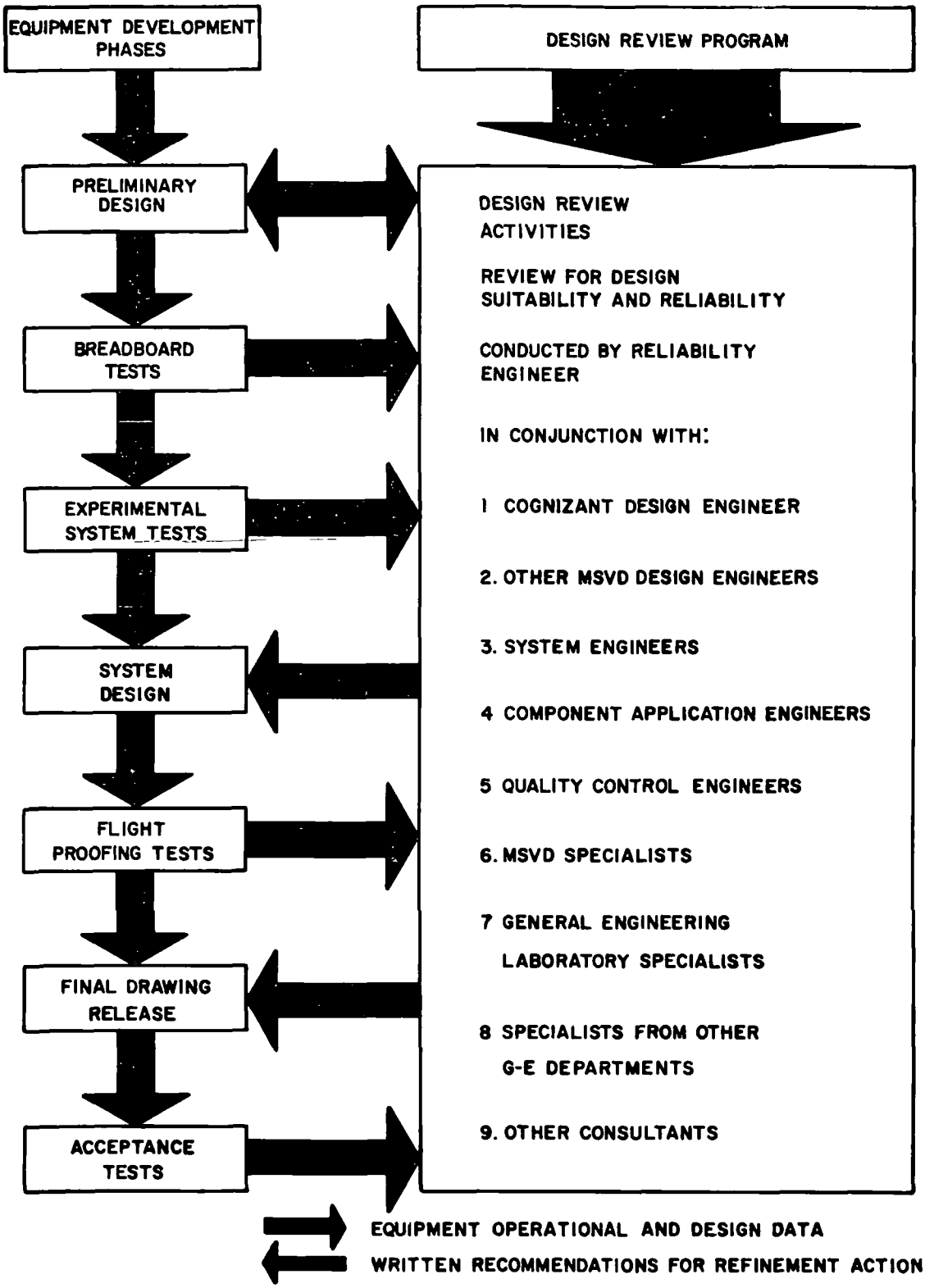


Figure I-5-2 Design review

provisions for preventive maintenance, and provisions for ease of maintenance. Minutes will be prepared and issued on each component design review held.

A reliability analysis will also be performed on each equipment prior to its design review so that a report of the analysis may be available for discussion as part of the design review.

5.3 RELIABILITY MEASUREMENT

The objective of the Reliability Measurement Phase is to provide through an environmental test program, test specification, and test data control, functional data on the performance capabilities of the design. The activities that are associated with this phase are the establishment of adequate test requirements and preparation of detailed specifications, a qualification test program, accumulation of test data, and failure reporting and analysis.

5.3.1 Specification Review

Specifications prepared for all levels of equipment will be reviewed to assure that they are compatible with system requirements. The responsibility for their preparation, review, and issuance is contained in the Department Instruction for Specifications.

5.3.2 Qualification Test Programs

Although system reliability is achieved through basic design, a test program is required to measure the degree of reliability attainment. The reliability program is directly concerned with equipment design capability, or qualification test.

The qualification program includes component qualification tests and in-house system tests designed to be a complement to design qualification tests. It is a function of these tests to uncover any design, specification or interface inadequacies, while demonstrating the system's ability to perform its intended function under

anticipated environmental conditions, and to establish that ultimate capability. The component qualification program, in conjunction with in-house system field, and flight tests, provides data for evaluation of equipment reliability, while proving design capability and performance. Feedback of modes of failure from the test program enables the design operations to make any necessary corrections. Tests are planned which provide the proper amount of information for effective evaluation of the product and its reliability. This is accomplished through the Intergrated Test Programs, which has been effectively operating within the Missile and Space Vehicle Department.

The first step in test planning consists of establishing the internal and external environments of the system. A report is issued early in the program, listing each component, the environment that the component will experience in flight, and the functional requirements of the component. The Integrated Test Program also provides for the review of environmental test requirements, and for the evaluation of the test results. The quantity of components to be subjected to qualification, and other tests necessary to demonstrate the required reliability are specified.

The Integrated Test Program also provides a means of formally qualifying equipment that has demonstrated adequate design capability to perform its operational requirements. The planned tests are sufficiently comprehensive to allow detection of important modes of failure.

Integrated Test Program Boards will be established for qualification of components and in-house qualification of systems. The functions of the boards shall include:

1. Review of test specifications for conformity to program requirements, uniformity of test requirements, and adequacy as bases for qualification of equipment.

2. Review of test data derived from component qualification tests.

3. Review of requests for waivers of or deviations from specification test requirements.

4. Decisions to qualify equipment, or to withhold qualification based upon results of testing.

Boards shall be composed of representatives of operations concerned in design and production of equipment; for example, quality control, design engineering, stress analysis, systems evaluation engineering, etc.

Each equipment specification specifying component qualifications tests to be accomplished, or changes thereto, will be submitted to the responsible board for approval prior to the commencement of any component qualification test program.

When a unit has completed its qualification tests, the engineer responsible for the test will be required to supply copies of each data sheet to the chairman and to each Board member. Each member will review these data sheets in detail prior to the meeting, at which the sheets will be formally acted upon. The Board may accept the test data, and thereby confer a department position relative to the equipment concerned that it is fully qualified to formal status. If the Board may accept the test data, and thereby confer a department position relative to the equipment concerned that it is fully qualified to formal status. If the Board rejects the test data, it will provide instructions relative to what must be done to secure qualification. These instructions may range from requiring certain additional data which was not provided to requiring that certain design changes be accomplished and the entire test program undertaken anew.

Detailed procedures governing the boards are contained in the Department instruction on the qualification of equipment. Integrated Test Program Board relationships are shown in Figure I-5-3.

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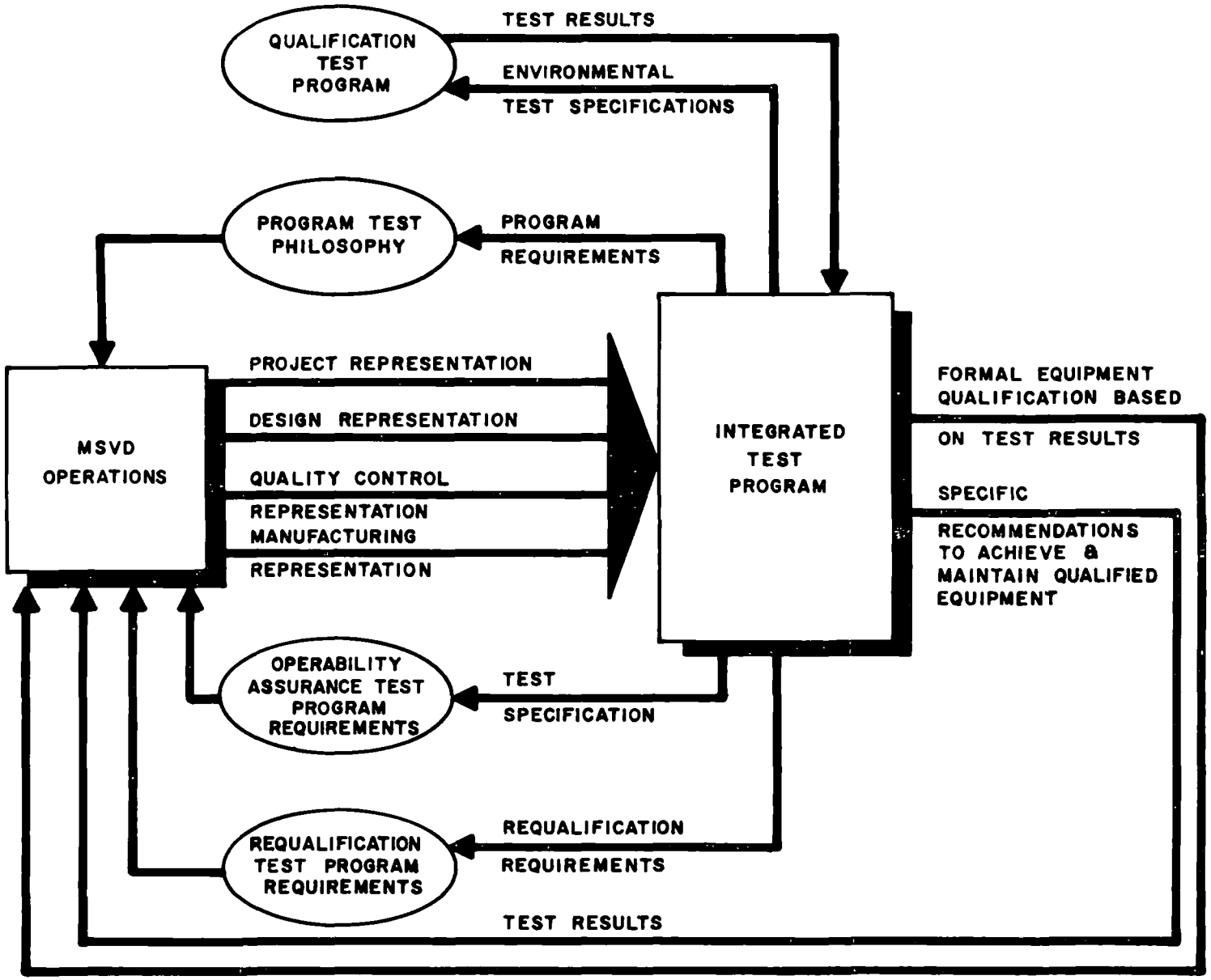

Figure I-5-3. Integrated test program board relationship

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5.3.3 Operating Data Accumulation

Operating data will be accumulated as shown in Figures I-5-4 and I-5-5. Test data will be accrued and processed as detailed in the Reliability Test data Accumulation Specification 118A1678. In accordance with the specification, a detailed operational log will be maintained for all equipment tests. This log, as illustrated in Figure I-5-6 will show all accrued test time on the equipment, as well as the length of each test period, the nature of the conducted tests, and the test environment, including the period of time the equipment was subjected to each environmental stress level. These data will be analyzed with other available reliability data in determining the equipment reliability and modes of failure.

Upon introduction of the Integrated Test Data Sheets, all reliability test data will be recorded. These sheets will include all the information required by Specification 118A1678. These sheets will be sent to the Quality Control Data Processing Operation where the information will be processed for computer use in accordance with existing data processing procedures. The data will be utilized in the equipment reliability analysis as described in the section on Reliability Analysis.

5.3.4 Failure Reporting and Analysis

Failure reporting and analysis will be accomplished by all vendors, in-house activities, and field test sites as illustrated in Figure I-5-7. Failure reporting will be required at the part level and on component acceptance, qualification, flight proofing, and all subsystem, system and field tests. The reliability engineers will be assigned at in-house and field test sites to monitor all tests, and assure that failure reports and reliability data sheets are accurately and promptly filled out and processed. The Reliability Operation will review each failure report and classify each failure as "critical," "major," or "minor" in accordance with the activity and to point out particularly serious problem areas where corrective action has not been completed. The reason for failure analysis and the completion of corrective action will also be documented in the Monthly Failure Summary Report similar to the one shown in Figure I-5-8.

All failures will be investigated and formal failure analyses will be conducted on critical and recurring failures. A failure analysis board will review the failure report, the physical hardware, the tabulation of previous failures, and associated drawings as required. This Board, composed of the cognizant design engineer, a Quality Control engineer, a components parts engineer, a systems engineer, and technical specialists as required, will recommend corrective action. Minutes will be prepared and issued on each failure analysis that is held. Follow-up meetings will be held to assure that corrective action has been accomplished.

5.4 RELIABILITY MAINTENANCE

The objective of the reliability maintenance phase is to provide assurance that the inherent equipment reliability is maintained in the operational systems. This will be accomplished through special manufacturing and quality control methods, vendor surveillance, and design-change control.

5.4.1 Quality Control Co-ordination

The manufacturing and quality control activities will include special manufacturing procedures, special inspection techniques, operability assurance testing, and field checkout. A reliability engineer will assist manufacturing and quality control in these tasks.

5.4.1.1 MANUFACTURING

The importance of the manufacturing and inspection functions cannot be overestimated. Each item produced for the APOLLO program must be in accord with its specifications and drawings. Such a high quality can be achieved only by analysis and control of every aspect of manufacture. Controls will start with raw materials, parts and progress through every aspect of fabrication and inspection cycle.

Control of raw materials will be accomplished by preparation of detailed specifications for each material to be procured These specifications will establish

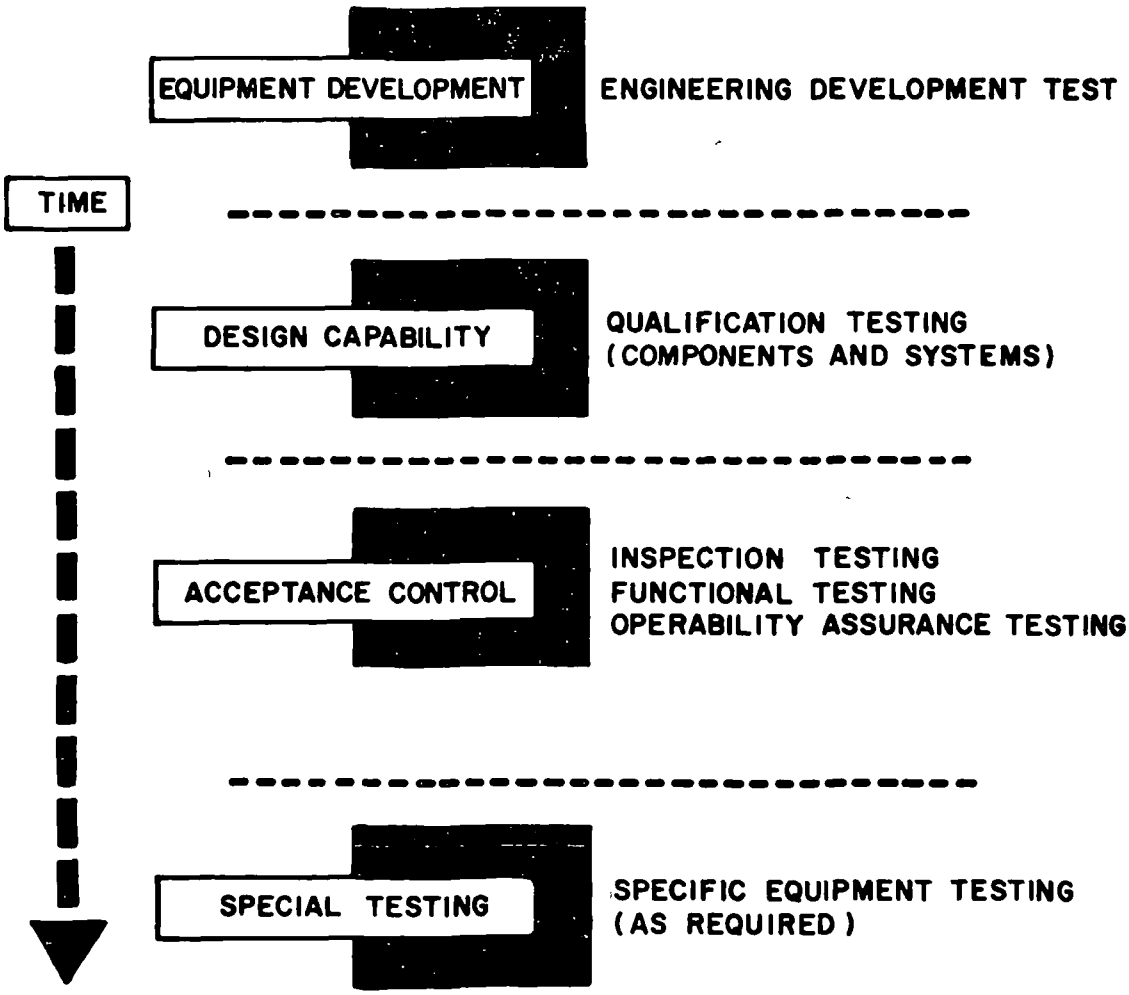

Figure I-5-4. Development test data

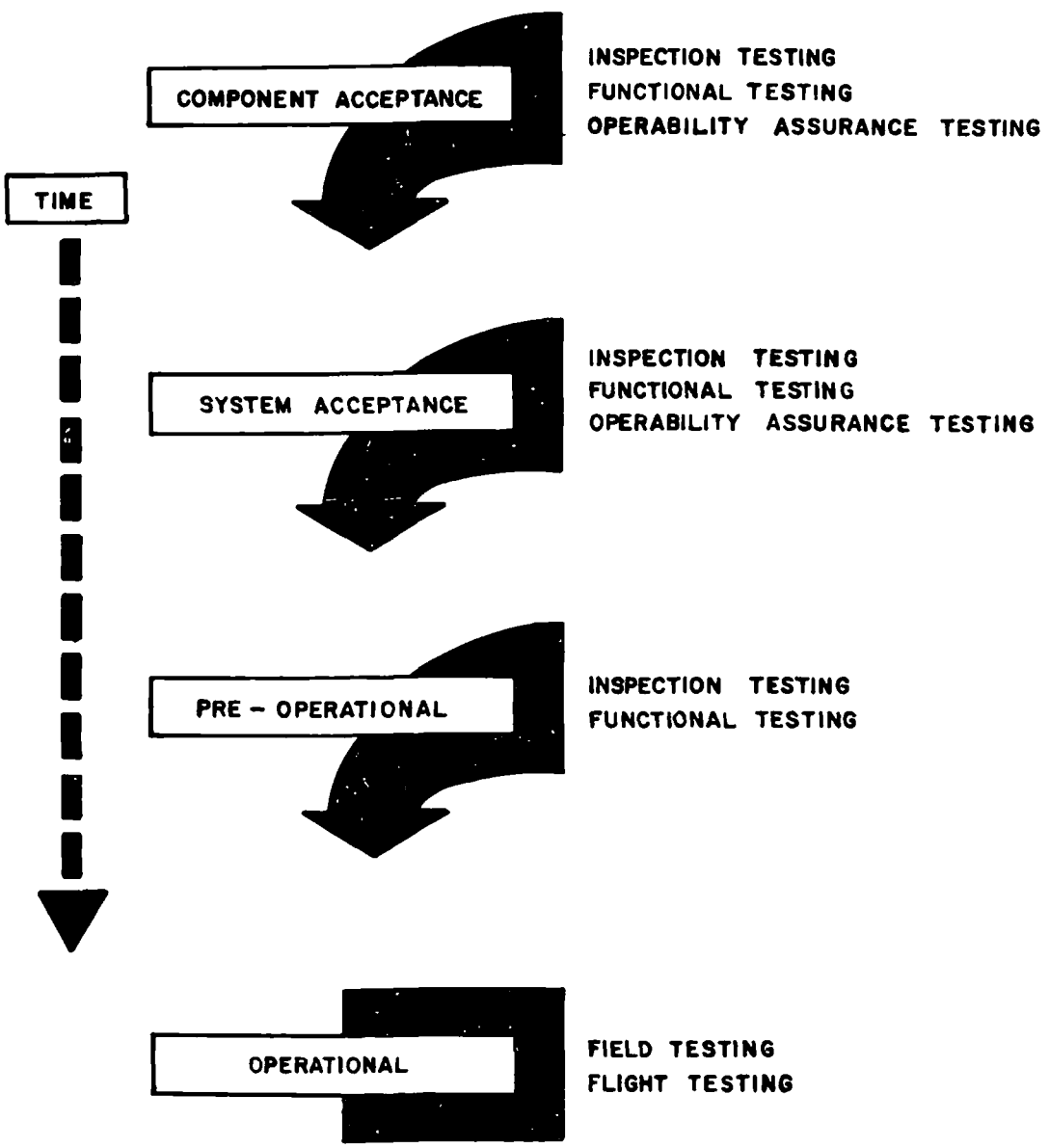

Figure I-5-5. Operational test data

APOLLO

RELIABILITY TEST DATA

ACCUMULATION & RECORDING

	SYSTEM IDENT					COMPONENT IDENTIFICATION												TEST DESCR				TEST RESULTS											
									DRAWING NUMBER													OPERATING					NON-OPERATING						
DATE	SYSTEM	MARK	MOD	SERIAL NO	SUB-SYSTEM	NAME	IBM IDENT CODE NUMBER	PREFIX	LETTER	SUFFIX	P OR G	P OR G NUMBERS	REV	CONFIG CODE	G E SERIAL NUMBER	VENDOR NAME CODE	VENDOR SERIAL NUMBER	LEVEL OF TEST	TYPE OF TEST	TEST ENVIRONMENT	TEST SITE, FAC OR ORG	H	M	S		FAILURES	TIME H	TIME M	TIME S	CYCLES	FAILURES	FAILURE REPORT NUMBER
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33

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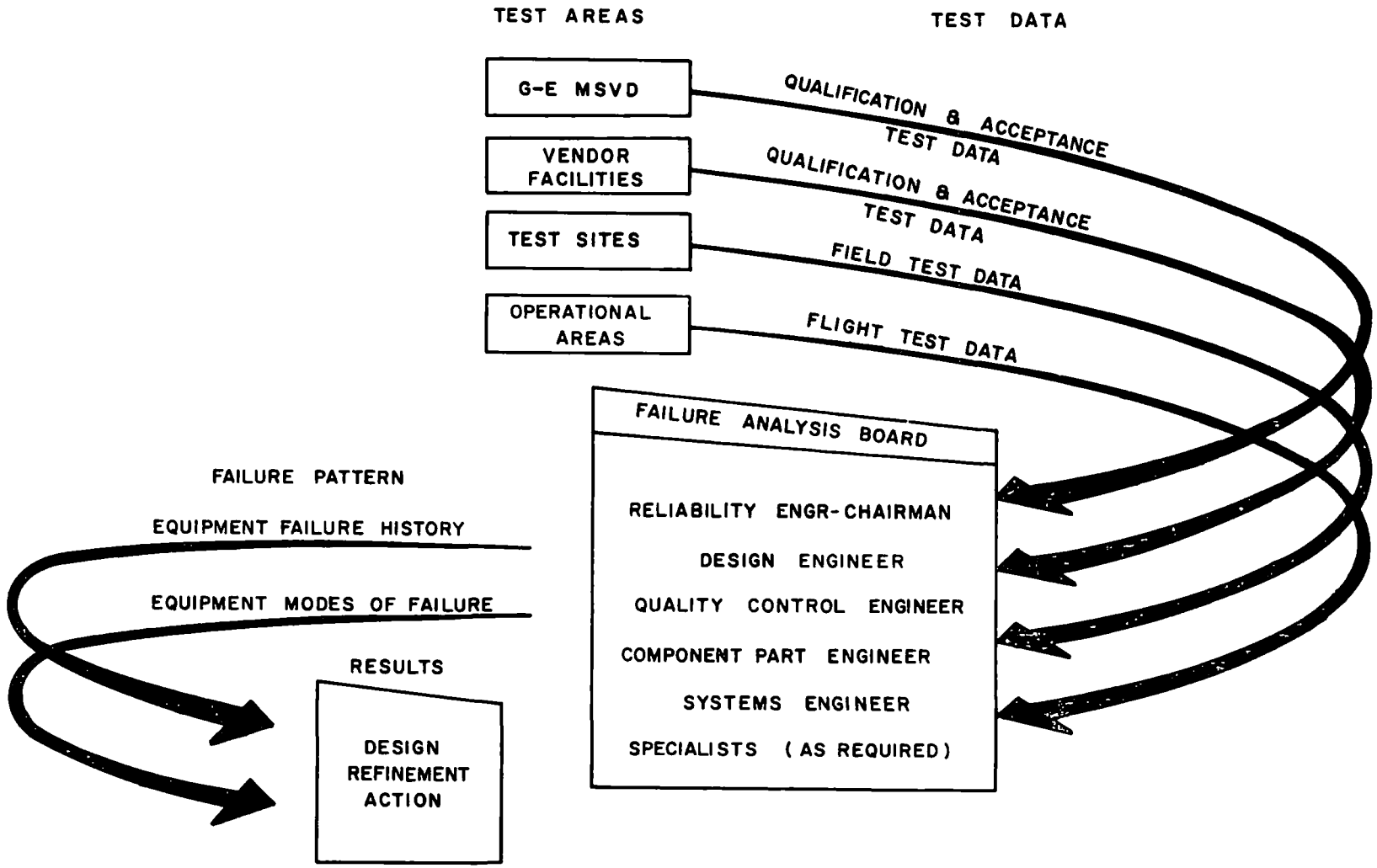

Figure I-5-7. Failure reporting system

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FAILURE SUMMARY REPORT

Program *Project "A"* Design Engineer *M. J. Jones* Drawing Number *100B200G2*

Manufacturer *Effective Engineering Co.* Q C Engineer *J. T. Smith* Equipment Name *Pressure Detector*

Test		Environment	F/R No.	Serial No.	Failure		Description of Failure (Excerpted from Failure Reports)	Failure Analysis			Corrective Action	
Activity	Program				Date	Class		Required	Report No.	Results	Document No.	Description
Component	Qual	Post Hi-Temp	21734	4	1/9/59	Minor	Operated at 0.5 amps	No				No action required unless repeated
Component	Qual	Post Sand & Dust	V01489	5254	12/6/58	Critical	Failed to actuate	Yes	A–469	Poor vendor quality	219–312	MSVD has tightened up vendor surveillance
Component	Qual	Vibration	V01582	5257	12/6/58	Critical	Failed to actuate					
Component	Accept	Ambient	V03415	5524	1/11/60	Minor	Leaks oil	Yes	A–471	Unrealistic torque requirements	219–196	Test instructions have been rewritten
Component	OA	Vibration	V03416	5520	1/11/60	Minor	Leaks oil					
Component	Accept	Ambient	M02924	5522	1/12/60	Minor	Operating pressure high	Yes	A–500	Defective test equipment	219–412	Test equipment repaired
Component	OA	High Temp	V03030	5523	1/11/60	Major	Input Shorted					
							1 February 1960					
Subass'y	Accept	Ambient	20155	5347953	12/10/59	Major	No output	Yes		Broken wire under potting		Repaired
Component	Qual	Post Accel	25318	29	11/3/59	Major	Intermittent open	No		Inadequate design	636–117	Drawing changed
Component	Qual	High Temp	21051	203	11/3/59	Minor	Actuation force too high	Yes	A–323	Design and/or vendor quality		
Component	Re Qual	Post Low Temp	25194	5479687	11/27/59	Minor	Actuates at 758 mm Hg	No				
Systems	Accept	Ambient	29743	111	12/2/59	Minor	Actuation point out of tolerance	No				
							1 March 1960					
Component	Qual	Low Temp	25188	102	1/3/60	Major	Won't operate at –65 degrees F	Yes	A–355	Inadequate test set-up	219–324	Test set-up redesigned
Component	Qual	Low Temp	25189	105	1/3/60	Major	Won't operate at –65 degrees F					
Component	Qual	Low Temp	25190	106	1/3/60	Major	Won't operate at –65 degrees F					
AMTR	Hangar	Ambient	204-108	1	12/2/59	Minor	Damaged	No				Workmanship
Systems	OA	Post Hi-Temp	M02928	4	2/12/60	Major	Low insulation resistance	Yes	A–384	Undetermined	PIR	581P398–6 Unit dried out and was operated successfully
AMTR	Hangar	Ambient	30164		2/15/60	Minor	Serial number missing	Yes	A–392	Nameplate torn off in shipping	312–164	New nameplate now being used which eliminates problem
							1 April 1960					

Figure I-5-8. Sample page of a failure summary report

detailed requirements for the physical, chemical, metallurgical, electrical, mechanical, and other significant properties. Every batch, lot, barrel, coil, or other appropriate unit of raw material will be subjected to such testing and inspection as may be necessary to establish compliance with the requirements of the appropriate specification. While such tests and inspections are in process, the remainder of the material will be suitably marked and placed in a bonded area where it will remain until all tests and inspections are satisfactorily completed. The results of tests and inspections will be tabulated on forms convenient for transport with the material through assembly. These forms will accrue through successive stages of assembly and test into a log of the finished vehicle, wherein the history of each part and component installed shall be readily available for review by quality control and other cognizant operations. Each procedure or instruction will be constantly reviewed, and the individuals working with these documents will be encouraged to make suggestions for changing them to improve the processes. Any recommendation so made will be answered in writing by the engineer responsible for the document. A copy of this answer will be given to the individual making the recommendation and one will be given to his supervisor.

All manufacturing and inspection tools, gages, machines, and equipment will be subjected to thorough inspection and calibration at periodic intervals as dictated by the nature of the equipment and its frequency of use. Reliability Engineers will participate in assuring the maintenance of the reliability requirements in the manufacturing cycle. Their functions will be the following:

1. Represent reliability on the Industrial Survey and Make Capability Study teams.

2. Work with manufacturing in the development of reliability practices and procedures.

3. Assist manufacturing, Q.C. & T. and manufacturing engineering in determining the adequacy of present practices and procedures for maintaining reliability requirements.

4. Integrate reliability activities with manufacturing and Q.C. & T activities.

5.4.1.2 ULTRA-CLEAN ASSEMBLY AREA

It has been found that apiece of lint small enough to be scarcely visible can be responsible for an intermittent short circuit in an electron tube. Similarly, a speck of dust inside a gyroscope or miniature potentiometer can disastrously alter the flight performance of a missile, and contamination introduced into the lubricant of small bearings can hinder the operation of moving parts and reduce reliability. As a result, studies will be conducted by Manufacturing with the assistance of Quality Control and Reliability Technical Requirements to establish the extent of need for ultra-clean assembly areas for the APOLLO program.

The Instructions and procedures which are prepared to define the manufacturing and testing tasks will have to be considerably more detailed and numerous than has been necessary for previous programs. Q.C. & T. will be responsible for preparing a detailed written procedure for each task in manufacturing and testing. These procedures will specify and fix procedures wherever possible. Examples of the type of detail required are to be found in the instructions provided by the manufacturers of electronic kits where a check list is provided for each step including: Tools required, and when desirable, a description of their use, cutting wire to length, stripping insulation, soldering one end of a wire, soldering the second end, and placing vacuum tube in its socket.

By developing such detailed instructions and requiring each step to be checked off when completed, the employee performing the task will be required to check and double check and will be impressed with the necessity of each step being performed *perfectly*.

5.4.1.3 LOT CONTROL

Each lot of raw material will be assigned a lot number immediately upon receipt from the supplier. All documents relating to raw materials will show the appropriate

lot number. Approved lots of raw material will be suitably marked and packaged to prevent damage or contamination, then retained in a limited access bonded area until used. If the material is time sensitive, it will be retested and reinspected at the correct intervals during storage as specified by the specification for the material. Access to storage areas shall be denied to unsupervised shop personnel, and written requisitions shall be required to withdraw material. Records of such transactions shall be retained.

Parts will be controlled in a manner similar to that employed for raw material. Each part to be procured will have a detailed specification and upon receipt of will be subjected to 100 percent test and inspection to ascertain that the part complies with every detail of the specification. These tests and inspections will include non-destructive techniques such as x-ray, ultrasonic, fluorescent inspection, etc. wherever applicable. Relays and larger devices will be assigned individual serial numbers while resistors, capacitors (the small sizes), diodes, transistors, etc. will be handled on a lot basis. In handling the smaller parts, special trays will be used to mount a convenient number of single parts for testing and storage. The results of all tests and inspection will be recorded with actual values being entered on the data form. Where x-rays are taken, only an entire lot or an individual serial numbered part will be taken, and the photograph will be retained on file with the rest of the data on that lot or part. Only parts obtained from bonded stock will be employed in assembling APOLLO components.

Wherever material or parts are taken from bonded stock for the fabrication/assembly of APOLLO equipment, the drawing number and lot or serial number of each material and part will be recorded on the data sheet which will be filled out to document the task being accomplished. When a system has been assembled, these documents will provide information as to the material, parts, vendors, lot and serial numbers, of every part (including nuts, bolts, and rivets) and material comprising that system.

5.4.1.4 PROCESS CONTROL

A manufacturing process, either manual and mechanical, will be systematically studied to determine the norm and variance of each parameter significant to the quality or reliability of the product. These studies will form the basis for determination of the necessary control measures. Where existing processes require improvement to meet APOLLO reliability/quality standards, such studies will serve as a means for measuring the effectiveness of improvement efforts. No process will be presumed to produce satisfactory results until its adequacy has been proven.

Such proof will be combined with the development of the process procedure during which a trial run will be conducted to produce one or more products of the process. These samples will be subjected to such tests and inspections as are necessary to fully demonstrate the capability of the process. Also, these tests will be used to develop non-destructive test criteria to be employed in testing all products of the process during subsequent production. During the trial run on assembly processes, optimum inspection points will be developed. No assembly will be permitted to proceed beyond an inspection point until the required inspection is accomplished.

Each individual assigned a task in the manufacture or inspection of APOLLO equipment will be trained for the particular task to which he is assigned. No individual will be permitted to perform any task associated with APOLLO production hardware until he has demonstrated a capability of performing the task in such a manner as to constantly produce a high quality product. Each piece produced by an individual in training will be inspected by a qualified inspector who will have been studied for percentage effectiveness.

The development of the initial instructions or procedures will be the responsibility of manufacturing engineering and quality control engineering. The importance of these documents is such, however, that it will be necessary to set up controlled experiments to verify the adequacy of each. This verification will be accomplished by techniques such as selecting the newest and least experienced individual in the

area where the work will be accomplished and having this individual attempt the task specified with no other instruction provided.

Any questions or mistakes will result in additions and modifications to the instruction or procedure. The check list for each item produced or tested will be signed and dated by the individual completing the task. It will be approved by the appropriate inspector, supervisor, or engineer and will accompany each piece of hardware. The check list used for assembly operations will contain provision for noting the serial and/or lot number of every item installed in the equipment during assembly.

An instruction or procedure of the type described will be required for every operation performed in-house except for machining operations. In these cases, an inspection check list will be required and the inspector will be required to check off each item on the check list by inserting the value actually measured. These check lists will have the limits of each characteristic to be measured printed on the list.

Assembly of any item from the level of a relay, stepping switch, vacuum tube, etc. will be accomplished only in accordance with a detail procedure of the type described herein. Each inspection and each test of hardware, down to the resistor, capacitor relay, transistor level and through the systems level will be accomplished only in accordance with such a detailed procedure and check list.

5.4.2 Vendor Reliability Program

MSVD will employ special procedures for the selection and control of vendors, to obtain the same high equipment reliability as is consistent with in-house design, manufacture, and test. The following special documents will be used to obtain this objective:

1. Vendors Reliability Specification GE-MSVD #146A9550.
2. Make or Buy Procedure and Structure.

3. Vendor Selection Procedure and Flow.

4. Control of Vendor Instituted Changes.

A source Selection Board will be established consisting of representatives from Reliability, Engineering, Quality Control and Integrated Test. The purpose of this board will be to select the vendors for design, manufacture, and test whose capabilities will provide the high level of equipment reliability that the program requires This board will be responsible for planning, organizing, integrating, and measuring the total make-or-buy vendor selection program. This group will set forth the nature and extent of controls necessary to assure that vendors supply equipment satisfactory to the requirements of the Department, and to define policies and procedures for establishment and maintenance of reliability programs at vendor facilities.

These reliability engineers will have the primary purpose of assuring the maintenance of reliability in the production cycle. They will serve as reliability representatives in all manufacturing and vendor activities affecting reliability. They will have the objective of developing an attitude of reliability conciousness in the manufacturing and vendor areas. Reliability achievement practice and procedures in the vendor area will be monitored by this group.

This Reliability Engineer will act in both an advisory and integrating capacity between Reliability Operations and all other operations affecting vendor reliability Vendor reliability requirements and specifications will be developed by this group.

5.4.3 Design Change Control

A Design Change Board will be formed for the program, consisting of a cross-section of Department personnel (Engineering, Manufacturing, Quality Control Test, Technical Requirements, Projects, and other operations deemed necessary).

The Chairman of this board will be the personal representative of the Program Manager.

The Design Change Board will review all proposed changes to assure:

1. Integration of the change among all MSVD affected operations.
2. A plan for the instruction of the change and disposition of any existing material.
3. Assure, prior to the approval, the change is in accordance with the program plan, is timely, and assure that its effects on cost have been considered.

5.5 RELIABILITY ANALYSIS

The objective of the reliability analysis phase is to establish equipment reliability prediction indices, based on analytical and statistical data as accrued throughout the APOLLO program. The analytical activities provided in this phase are statistical test planning, statistical test evaluation, and special analytical studies. A summary of the mechanized reliability program is included.

5.5.1 Statistical Test Planning

In order to provide adequate data for reliability prediction purposes, statistically significant operational testing will be specified and carried out on parts, components, and systems. These test data will be supplemented with the data from the system tests as they are conducted, and revised equipment operational reliability predictions obtained.

Equipment reliability status reports will be prepared and issued periodically. The procedures employed in generating the reliability status reports are detailed in the following section.

5.5.2 Statistical Test Evaluation

Test data from every test activity are fed into the high speed digital computer and processed and sorted into four separate reports

1. Report I. The major purpose of this report is to provide a summation of the test time each component has seen in each environment, the data of test, and the failure report number.
2. Report II. The major purpose for this report is to provide a summation of the test time a particular component type has been subjected to each environment, the quantity of components tested, and the number of failures per environment. This report places the data in the most convenient form for calculating the Equipment Reliability Status Report.
3. Report III. The major purpose of this report is to provide a summation of the test time and failures logged on each serialized component.
4. Report IV. The major purpose of this report is to provide a summation of the test time and failures logged on a component type. Report IV also indicates the number of components which have been tested.

The reports are to be available on a monthly basis and on an inception-to-date basis. The monthly reports will be identified as IA, IIA, IIIA, and IVA. The inception-to-date reports will be identified as I, II, III, and IV.

Equipment reliability status reports will be automatically generated and issued periodically. These reports will present a complete listing of equipment failure rates and reliability indices for the APOLLO components, subsystem and systems, for each anticipated environmental condition and over-all operation. These output reports will show equipment reliability status and reliability growth, which can be graphically presented over the development cycle. They will also point out areas where concentrated effort will provide management with a quantitative

measure for equipment reliability status while affording the design engineer an opportunity for any needed re-design early in the development program.

5.5.3 Special Analytical Studies

A detailed analysis will be performed by the responsible design engineer on each circuit employed in the APOLLO program. The purpose of this analysis will be to determine the stresses (electrical, mechanical, and environmental) which will be encountered by each component part employed in the program.

Upon completion of these studies, test planning will be carried out. Every effort will be made to utilize test information currently available within General Electric, NASA, or from Governmental or other industrial sources. Where insufficient information exists, tests will be planned which secure the unavailable information with a minimum of expense.

The test data and the information developed in the stress analysis of each circuit will be utilized, along with the de-rating curves in the component application manual, to arrive at failure rate estimates for the component parts. Component reliability analysis will be carried out by each design engineer at each step of the design development. A formal reliability analysis will be performed and a report of this analysis will be presented at the time of the design review of the subject component.

5.5.4 Mechanized Reliability Program

A mechanized reliability program will be prepared for the APOLLO program. It will be utilized to reduce data collected at the part, component, subsystem, and systems level of testing, in such a way as to establish reliability indices for equipment at these levels.

Figure I-5-9 provides a summary of the flow of information through the proposed mechanized data system. Design engineering has the responsibility of providing current information on the system, including a breakdown of the system into its

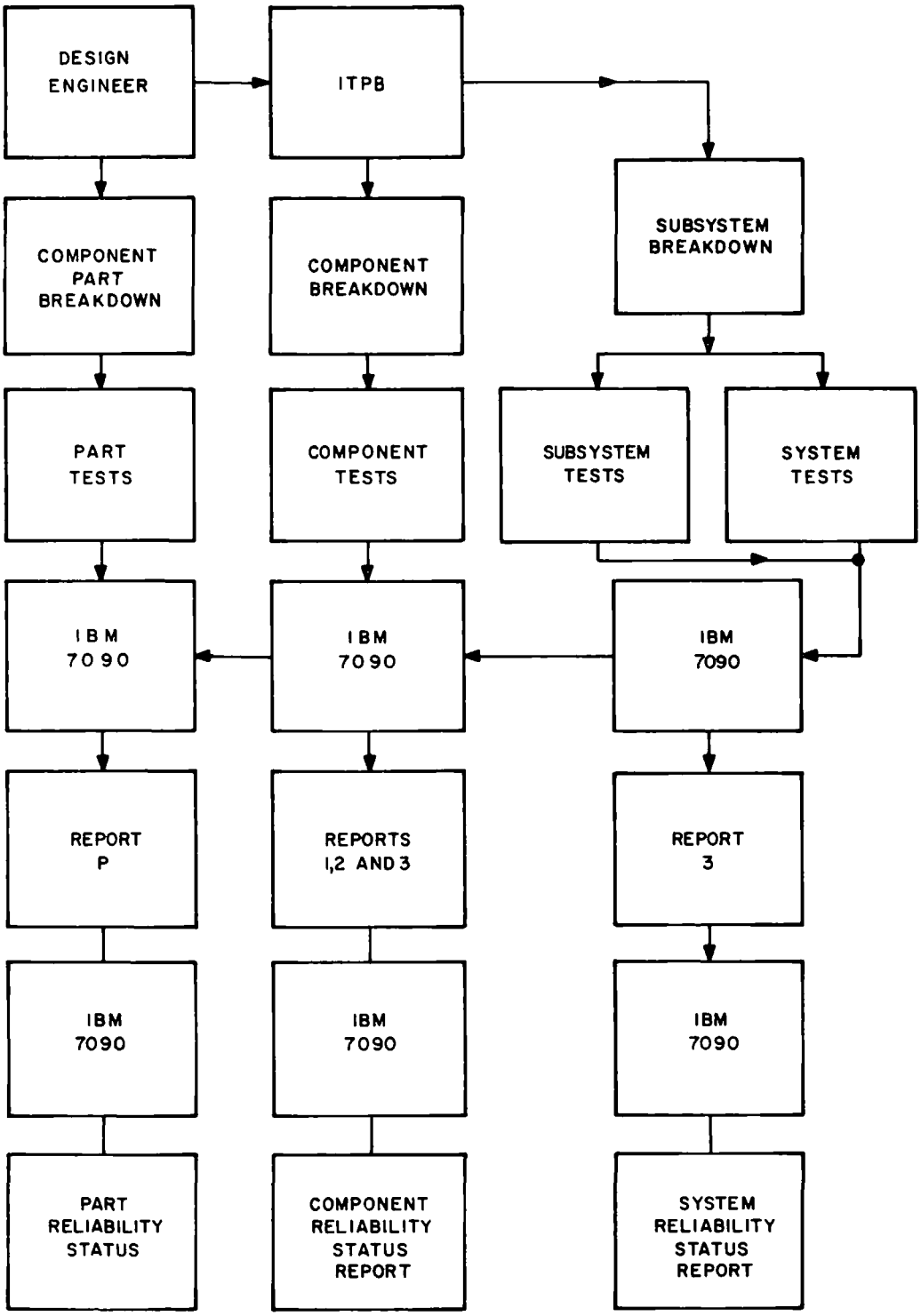

Figure I-5-9. Flow of mechanized data diagram

subsystems, a breakdown of each subsystem into its components; and breakdown of each component into its parts. These breakdowns must be current and accurate, as they provide the basis for the entire program. The information required in each breakdown will include equipment identification such as Military Standard (MS) number on parts. The manner of connection (series or parallel) will also be provided by the design engineer. Each month the Reliability Operation will issue a Failure Summary report listing all failures on equipment and indicating analysis conducted, and corrective action accomplished. This report will provide a complete account of each failure, the action taken to determine the cause of the failure, and the action taken to rectify the failure. Failure reporting will be conducted in accordance with MSVD Specification 118A1679, except that it will be extended to also include parts failures.

Failure Analysis will be conducted by the Reliability Operation in accordance with the requirements of MSVD Specification 118A1680.

A Failure Analysis Engineer will be assigned to each ten (10) components of the APOLLO System. In addition, there will be one Failure Analysis Engineer assigned to analyzing system failures, and at least one assigned to ground support equipment failures. These Engineers will study all documents pertaining to the equipment for which they are responsible, to become intimately familiar with every aspect of the equipment design, manufacturing, testing and use, and to identify possible failure modes. Specifications, test instructions and procedures, manufacturing processes and procedures, drawings, and design review reports are representative of the type of documents which the Failure Analysis Engineer will review and study. Each document will be reviewed with the assistance of appropriate specialists, to ensure that each mode of failure which might result is fully understood.

Whenever a failure occurs, the Reliability Engineer assigned to the particular test area will immediately notify the responsible Failure Analysis Engineer, and provide him with a detailed description of the conditions under which the failures occurred. The Failure Analysis Engineer will review the information folder on that particular component serial number, which will contain all procurement and test records on that particular component. In the case of repetitive or significant failures, a Failure Analysis Board as described MSVD in Specification 118A1680 will be convened, and the failure analysis conducted as specified in these documents. In all other cases, the Failure Analysis Engineer will determine the cause of failure and the necessary corrective action. He will prepare a detailed report which will document the history of the equipment up to the failure, the details of the analysis which he conducted, the conclusions arrived at, and specific recommendations for eliminating the cause of failure. He will receive all failed units within the area of his responsibility, under bond, immediately following failure. He shall supervise such dissection and analysis as he may consider necessary to establish the specific cause of failure. Where questions of doubtful fact, or unverified premises or conclusions exist, he will have the responsibility of verifying the cause of failure and determining the appropriate corrective action by such test or studies as he considers necessary. A list of each recommendation made on each failure analysis, and continuous followup to determine when corrective action has been completed and its effectiveness proven will be maintained. A report will be issued on a regular basis which will describe all completed items since the previous issue, and list each uncompleted recommendation. Quarterly reports will be prepared to show the over-all effectiveness of the failure analysis. The various tests performed, including qualification, re-qualification, acceptance, field, and flight, will be reported in accordance with the Department specification on data accumulation.

5.5.5 Reliability Prediction

The reliability prediction activities will provide the following data throughout system development.

1. Reliability information as to the component survival probability in each of the operational environments.
2. A determination of which components require immediate attention prior to their assembly in the system.
3. Data necessary for establishing the equipment survival probability in the combined operational environment.

6.0 Manufacturing Plan

The manufacturing plan, based upon the preliminary design described in the other volumes of this study, show how the APOLLO space vehicle, its components and the ground support equipment will be manufactured. The following paragraphs describe functions to be performed by manufacturing in accordance with the schedules given in Section 6.1.

This manufacturing plan is based on the D-2 design configuration of the APOLLO vehicle. It consists of an outer, semi-ballistic shaped, fairing structure and a propulsion module structure both of which are made of coated aluminum honeycomb sandwich material.

Housed within the outer fairing structure are the Mission Module and the Command Module. Both modules are designed to support human life in a space environment. They are interconnected by a passageway which permits access from one chamber to the other during flight missions. Both modules contain instrumentation and equipment.

The Propulsion Module as shown in Figure I-6-0 is attached to the aft end of the outer fairing structure and the entire assembly mounts on the Saturn C-1 or C-2 booster which has a payload interface diameter of 18 feet. The Propulsion Module contains all primary tankage, nozzles and a solar energy collector.

6.1 COMMAND MODULE MANUFACTURING PLAN

The Command Module is the portion of the space vehicle which is designed to return from the mission and from which the entire mission is directed. It is a double walled, NERV shape, re-entry vehicle made of an aluminum alloy approximately 8 feet long and 9-1/2 feet in diameter. Figure I-6-1 shows the inner chamber

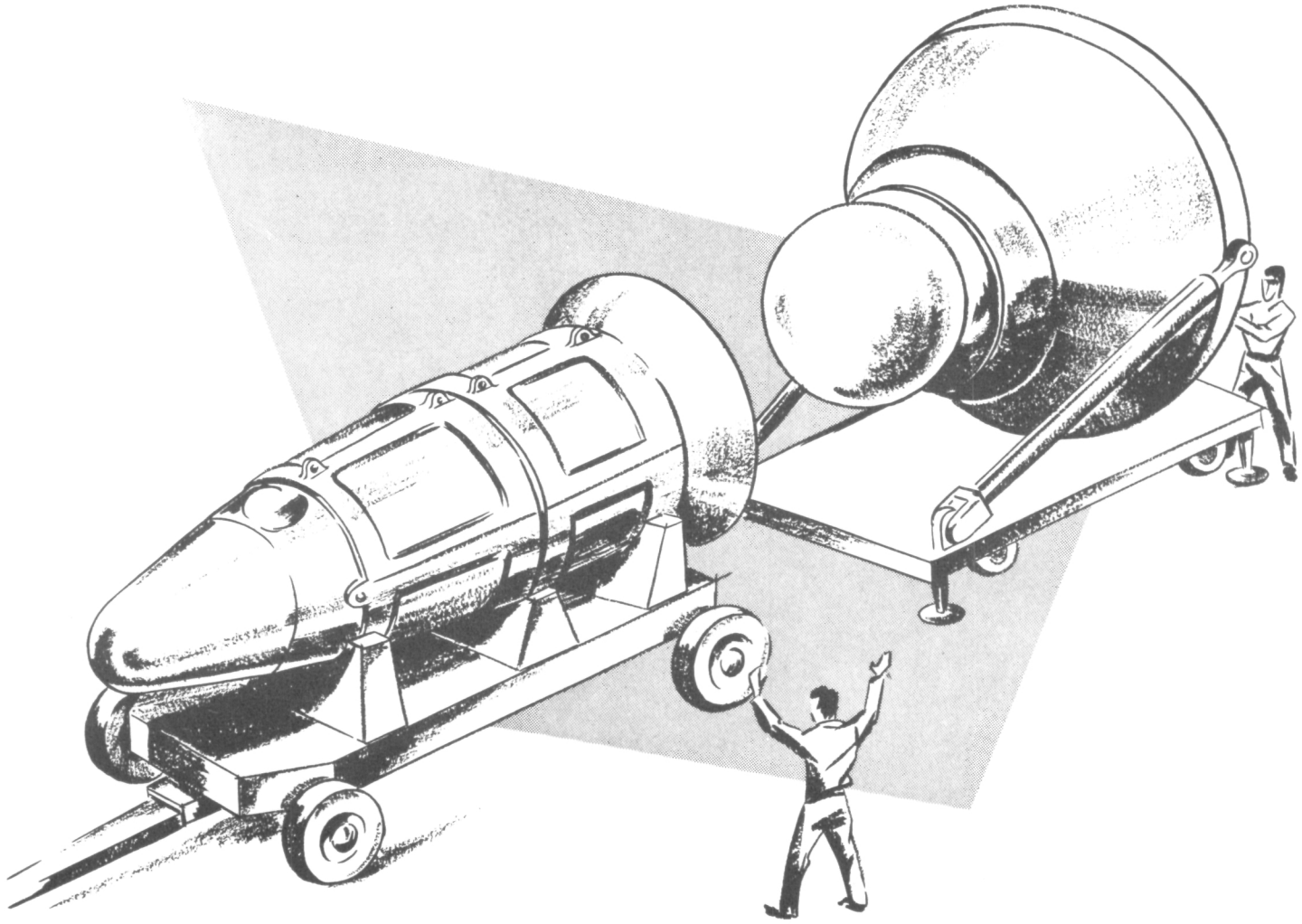

Figure I-6-0. Propulsion module being attached to outer fairing

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which is a welded pressure vessel, externally stiffened, designed to withstand an internal pressure of one atmosphere. The vessel is designed around the annealed strength of the alloy with no heat treatment after welding.

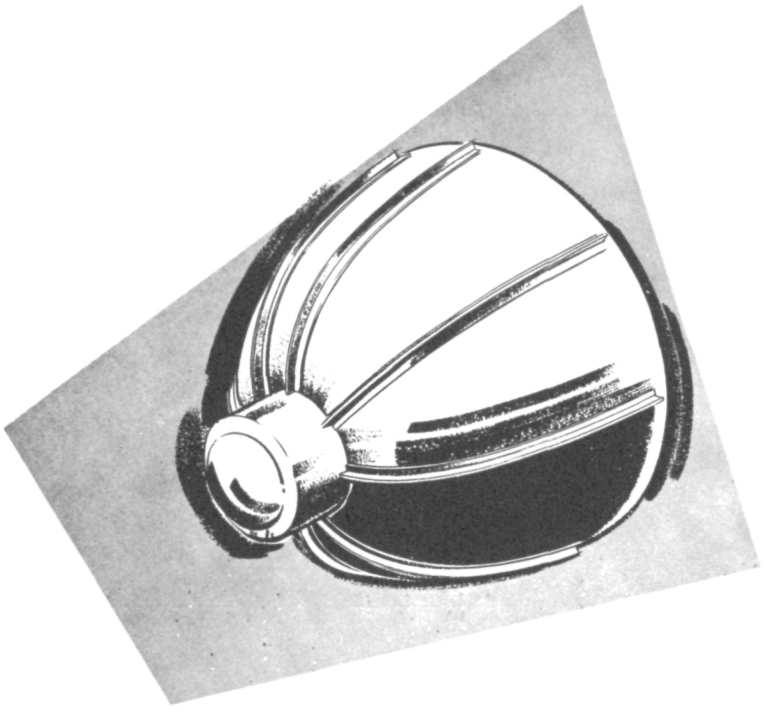

Figure I-6-1. Assembly of support beams-command module

External stringers will be stretch formed, as shown in Figure I-6-2, and set up in a fixture. The internal pressure skin will be made in gore sections by explosive forming or stretch forming and assembled by fusion butt welding to each other and resistance welding to the framework to produce a half chamber In the half-chamber condition, internal structure and modules can be installed easily without necessitating access through the operational hatchway provided at the forward end for personnel entry and access to the mission module.

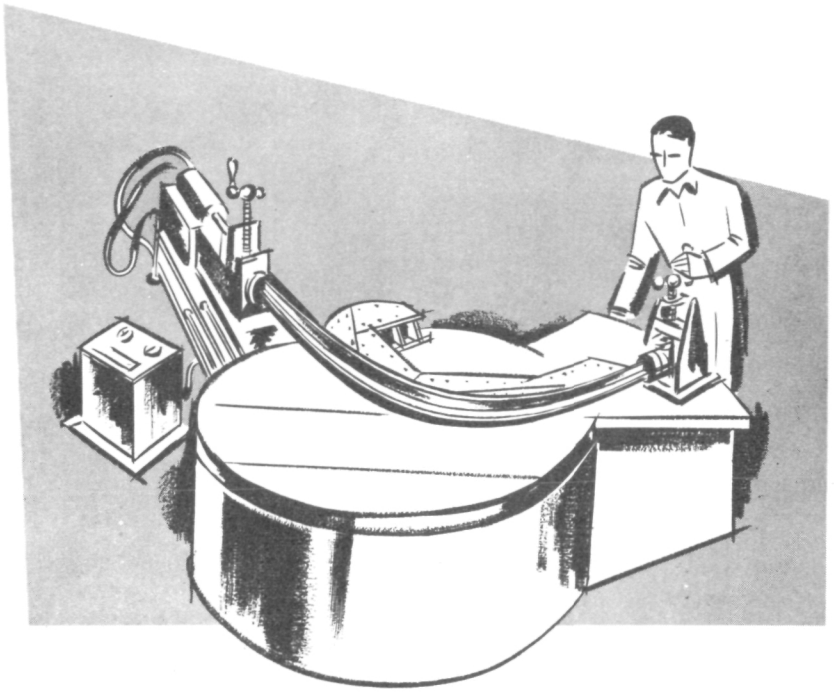

Figure I-6-2. Stretch forming stringers - command module

Subsequently the two halves of the inner structure will be married by fusion welding to produce an all welded, leak tight vessel as shown in Figure I-6-3.

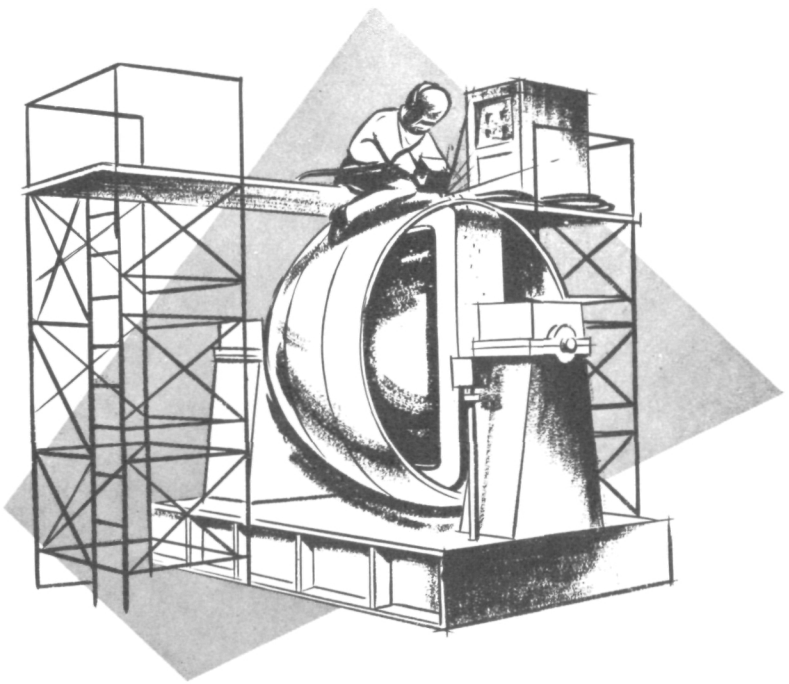

Figure I-6-3. Fusion welding the two halves of the command module inner structure

Crushable honeycomb panels for impact protection are added to the outer surface of the pressure vessel shield by adhesive bonding. As shown in Figure I-6-4, the outer aluminum skin consisting of a truncated cone, a dome and a moveable heat shield are added to the structure from the outside by flush head explosive rivets and fusion welding. The space between the two skins is divided into compartments to house insulation, parachutes, flares, and floatation equipment.

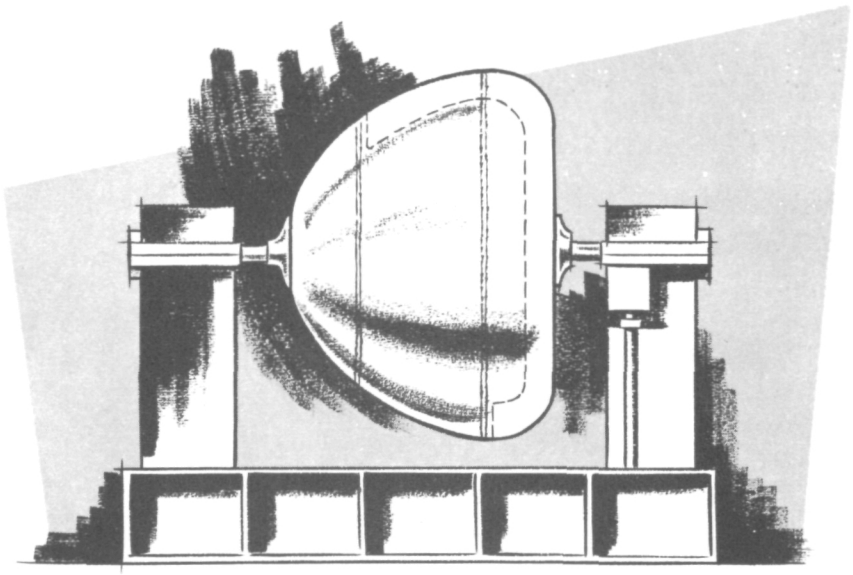

Figure I-6-4. Command module outer aluminum skin

The entrance hatch connecting the command module to the mission module will be made of an aluminum cylinder with a sealing flange for pressure sealing the bellows from the Mission Module.

This module will be attached to the space vehicle structure through a high strength steel support cone which is mechanically fastened to the aluminum structural ring welded into the pressure capsule skin structure.

A single control flap approximately 2-1/2 feet x 3 feet is hinged to the re-entry end of the Command Module. Pyrolytic graphite will coat all exposed surfaces of the flap. The entire Command Module will be ablation coated with gradually varying thickness on the external surface as shown in Figure I-6-5.

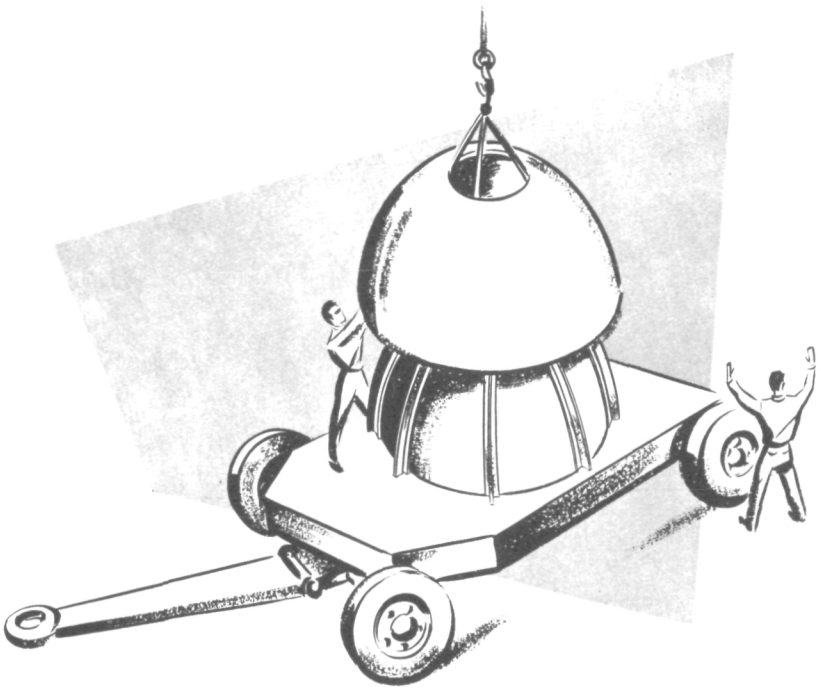

Figure I-6-5. Ablation coating the command module

6.2 MISSION MODULE MANUFACTURING PLAN

The Mission Module, shown in Figure I-6-6, is the second life support module in the vehicle, but is not recoverable. It consists of a welded pressure vessel approximately 10 feet long and having a maximum diameter of about 6-1/2 feet produced by joining aluminum conical frustums to each other and to stretch formed or explosive formed aluminum end closures. The pressure vessel will be structurally stiffened by welding in an internal structure framework made of stretch formed stringers and channels. The necessary internal structure to support instrumentation modules and all other equipment compartments will be welded in place.

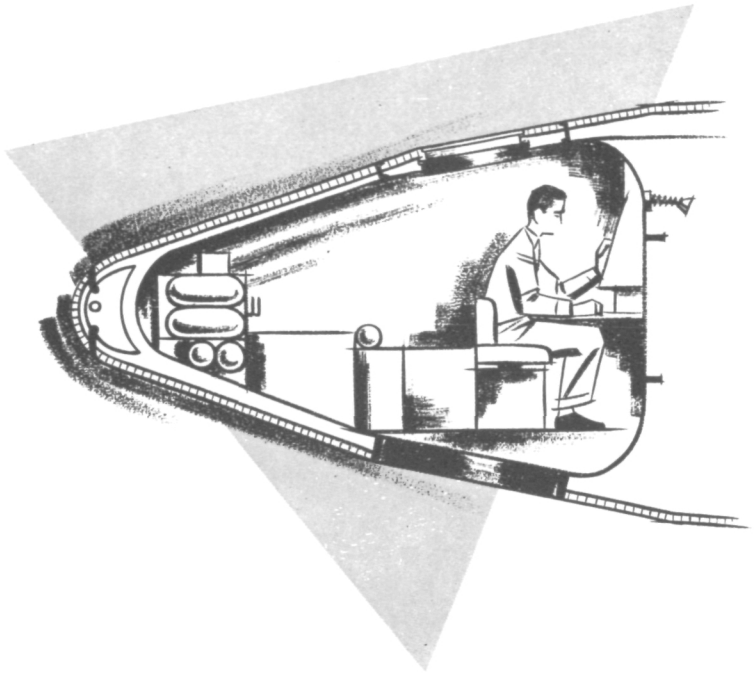

Figure I-6-6. Mission module

Located every 45 degrees radially around the circumference will be eight structural longerons which are welded to both the mission module structure and to a conical sheet metal portion of the outer shell structure of the vehicle. The structural load of both pressurized chambers will be carried to the outer vehicle structure through this arrangement. This portion of the outer shell is welded to the forward and aft sections of the outer structural fairing and is also coated with a temperature limiting ablation material.

The corrugated passageway and the high strength steel structural connecting cone are attached to the mission module in a fashion similar to the attachment to the command module previously discussed. The corrugated passageway will be under compressive load for sealing purposes while in position.

These items will be designed to separate from the command module and remain with the mission module when preparing for re-entry to the earth's atmosphere.

6.3 OUTER STRUCTURAL FAIRING MANUFACTURING PLAN

The outer structural fairing consists of forward and after conical sections. These are separated by and joined to the sheet metal outer skin which is attached to the mission module longeron structure. It is approximately 20 feet long and approximately 11 feet in diameter at its large end where it mates with propulsion module.

The forward section of the nose fairing consists of a truncated cone made of adhesive bonded honeycomb sandwich construction. The frustum assembly is made by sandwiching honeycomb core material between conical sheet aluminum skins, in a fixture designed to apply the necessary heat and pressure to the sandwich for bonding. Suitable edge attachments, shown in Figure I-6-7, previously produced, are bonded in place for the purpose of fastening the cone by fusion welding to adjacent parts. At the nose end of the outer cone, a spun aluminum cap will be welded in place by fusion butt welding. The aft end of the forward fairing section is welded to the mission module support cone in the same fashion.

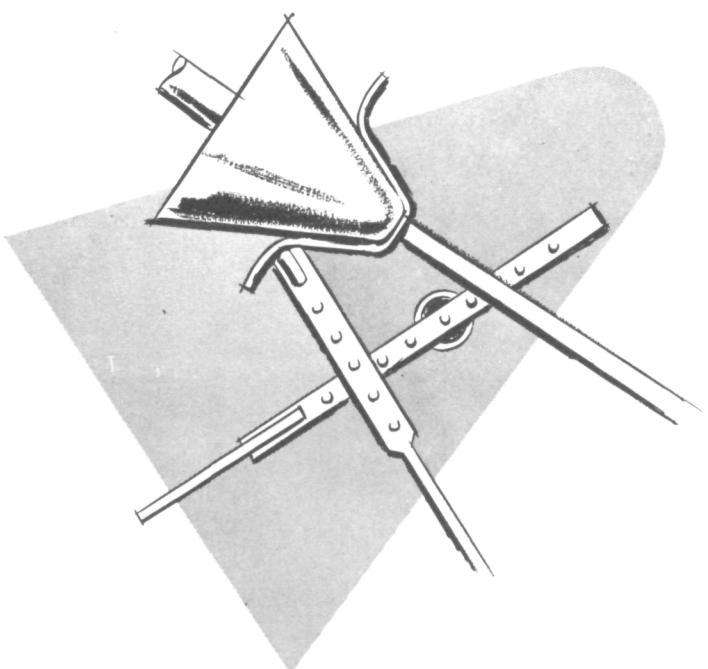

Figure I-6-7. Fairing edge attachments

The after sections of the outer fairing structure are also of honeycomb sandwich construction, produced on special heated and pressurized tools for adhesive bonding. These sections consist of a rear conical frustum, which mates to the propulsion module, and an intermediate conical frustum made of individual curved panels which mate to the outer cone of the mission module. Longitudinal and circumferential fusion butt welding are used for final assembly. This method of construction permits access to the command module support cone which joins the two pressure chambers by means of a pre-stressed riveted joint. Figure I-6-8 shows the fairing attached to Mission Module.

A protective coating to limit the metal surface temperatures to 200 - 300 F will be applied to the entire surface of the outer structural fairing.

Support and spacer hardware in the form of hat sections made of beryllium with elastic bumpers mounted to contact the command module are mounted on the inside of the outer fairing structure through mechanical attachments to inserts bonded into the sandwich for this purpose.

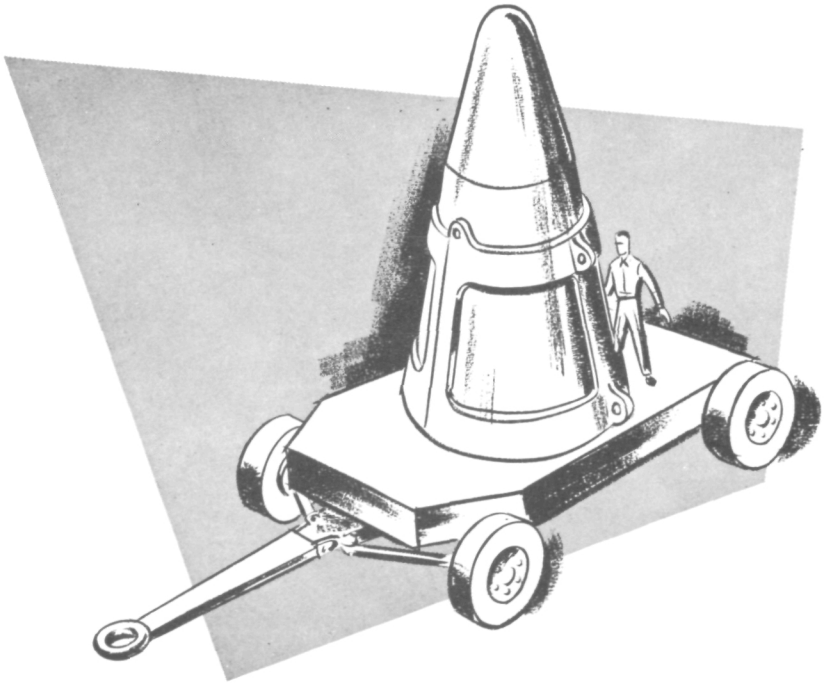

Figure I-6-8. Fairing attached to mission module

6.4 PROPULSION MODULE MANUFACTURING PLAN

Figure I-6-9 shows the Propulsion Module which consists of a conical aft section with a maximum diameter of 18 feet housing the solar energy collector and motors, and a cylindrical forward section housing the fuel tanks. The Propulsion Module mates with the outer fairing at its small end and with the Saturn booster at its large end.

The external construction is of honeycomb sandwich. Internal stiffener rings and longerons are fastened mechanically to bonded-in inserts for the purpose of supporting internal components such as rocket nozzles, tanks and other propulsion gear. External sheet metal pods to house abort rockets are also fastened to the sandwich structure mechanically by means of bonded-in inserts.

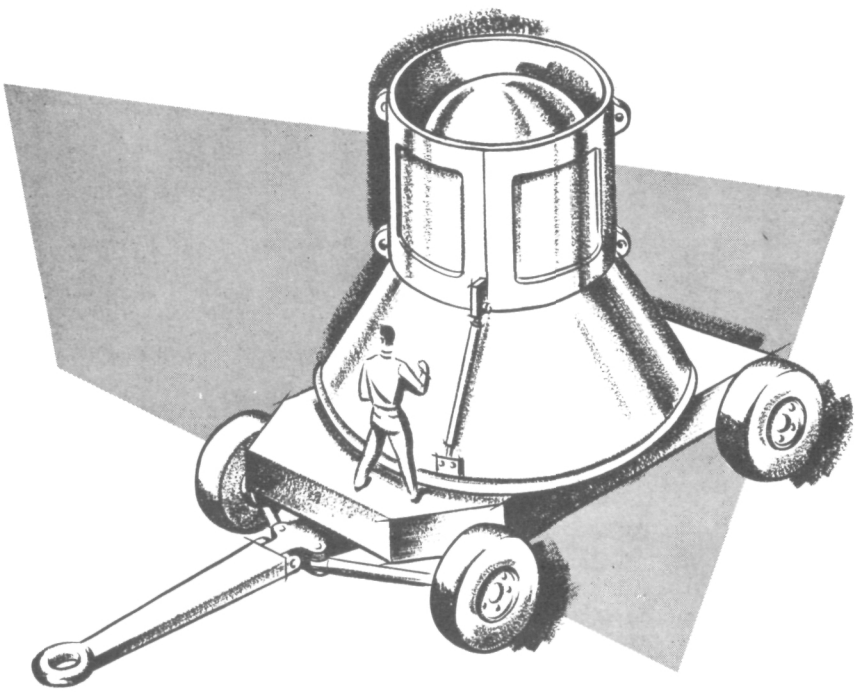

Figure I-6-9. Propulsion module

The conical section will be made in several parts so that the maximum dimension will not exceed 12 feet, thus avoiding special transportation methods for the module

prior to final assembly. The cylindrical section will be in 4 adhesive bonded honeycomb sandwich panels At the final assembly station, longitudinal and circumferential welding will be employed to complete the vehicle.

This plan contemplates manufacture by a subcontractor of the Propulsion Module

6.5 MATERIALS PLAN

It is presently contemplated that the major material of construction used in the APOLLO vehicle will be the Aluminum Alloy 5056. Adhesive bonded honeycomb sandwich will comprise most of the external surface. The outside surface temperature of the structure will be limited to 200 - 300 F through the use of protective coatings attached. The pressurized compartments including stiffening structures will be built from the same aluminum alloy.

Mechanically beryllium hardware will be employed as part of the internal structure wherever permissible to aid further in weight reduction.

Ablation coatings, and pyrolytic graphite will be used on the surface of the command module which will be subjected to extremely high temperatures during the re-entry phase of the mission

Insulation against heat and cold will be required for the crew chamber which will be maintained at a temperature of 75 - 85 F. This insulation would be of lightweight construction, probably a laminated blanket of vapor deposited aluminum on mylar sheet.

Tanks will be made of titanium, high strength steel or glass filament wound construction.

6.6 MAKE OR BUY PLAN

Figure I-6-10 presents a matrix of the Make or Buy Plan for APOLLO assemblies and subassemblies. The decision to make the item at MSVD or to buy it from an outside source was made considering the following factors·

1 Manufacturing and test facilities available at MSVD.
2. The manufacturing flexibility required.
3. Design firmness.
4. Cost.
5. Anticipated MSVD shop load
6. Proprietary nature of the item or related item

The Make or Buy Plan applies to those items which

1 Are principal components of the APOLLO vehicle
2 Cost $500 or more.

The Make or Buy decisions were accomplished in accordance with normal MSVD procedures which are consistant with Armed Services Procurement Regulation 3-902.

6.7 MANUFACTURING FLOW PLAN

Designs approved by Engineering begin their initial manufacturing phase in Planning. From here, Production Control channels all activities, as shown in Figure I-6-11 until the APOLLO is shipped

Before any manufacturing is started the Model Shop will construct a mock-up of the APOLLO and any specific parts that may present fit up problems or three dimensional visualization difficulties. Routing of wiring and tubing will also be tried out at this stage.

A truck siding provided along the supply dock brings raw material or components into the Receiving and Shipping Area. Inspected material moves to any of the four areas

1 Raw Stock & Storage
2. Subassembly Storage.
3 Q C. Parts Certification.

ASSEMBLY NAME	DETAILS	MATERIAL	MAKE OR BUY		PRIMARY MANUFACTURING OPERATIONS/OR REASONS FOR BUY
Outer Fairing Structure			M		Assembly Weld
		Temperature Limiting Coating	M		Mold, Bond and Cure
	Nose Cap	Aluminum 5056 Sheet	M		Spin
	Nose Fairing	High Temp Adhesive		B	Adhesive Bond
	a Conical skins b Honeycomb core	Aluminum Alloy Sheet Aluminum foil adhesive bonded		B B	Roll, Weld, Expand Specialized vendors are experienced and facilitized
	Stiffener Channels	Aluminum Alloy		B	Stretchform, Weld
Outer Fairing Structure Aft	Fairings	High Temp Adhesive Temp Limiting Coating	M	B	Adhesive Bond Mold, Bond and Cure
	a Conical Skins b Honeycomb Core	Aluminum Alloy 5056 Adhesive Bonded		B B	Roll , Weld, Expand Specialized vendors are experienced and facilitized
Mission				B	Assembly weld and rivet
		Temperature Limiting Coating	M		Mold, Bond & Cure
	a Frame, Channels b. Pressure vessel c Connector Tunnel d Longerons e Outer Skin f Outer Access Door	Aluminum Alloy 5056 Aluminum Alloy 5056 Aluminum Alloy 5056 Aluminum Alloy 5056 Aluminum Alloy 5056		B B B B B B	Stretchform, weld Stretchform or explosive form domes, roll, weld and stretch cones Purchase from vendors qualified to produce large bellows Shear, Brakeform, Weld Roll, weld, stretch, cut and assembly weld Adhesive Bond
	f 1 Skins f 2 Honeycomb core	Aluminum Alloy 5056 Aluminum Foil adhesive bonded		B B	Stretch form or explosive form Buy from qualified and facilitized vendor
	g Inner Access Door h Door, Connector j Support Cone	Aluminum Alloy 5056 Aluminum Alloy 5056 High Strength Stl	M M	 B	Explosive Form Explosive Form & Weld Limited number of steel parts justify purchase from qualified vendor
Command Module			M		Assembly weld and rivet
		Temperature Limiting Coating	M		Mold, Bond & Cure
	a Pressure Chamber	Aluminum Alloy 5056		B	Stretch form or explosive form and weld
	1 Support Channels	Aluminum Alloy 5056		B	Stretch form
	b Outer Shell				
	b 1 Cone b 2 Dome b 3 Shield	Aluminum Alloy 5056 Aluminum Alloy 5056 Aluminum Alloy 5056		B B B	Roll, Weld & Expand Explosive Form Stretch form or explosive form
	c Support Cone d Door, Connector e Control Flap	High Strength Stl Aluminum Alloy 5056	 M	B	See Support Cone Above Explosive Form & Weld
	e 1 Structure e 2 Coating	Super Alloy or Refractory Metal Pyrolytic Graphite	M M		Form, Weld and Machine
Propulsion Module				B	Buy complete module from propulsion vendor Construction suitable for ease of transport Includes structures, tanks, nozzles, and rocket motors
	Solar energy collector		M		Adhesive bond
		Aluminize		B	Aluminize by vendors who are facilitized
	1 Skins 2 Honeycomb Core	Aluminum Alloy 5056 Aluminum Foil Adhesive Bonded		B B	Stretch form Vendors are experienced and facilitized
Final Assembly			M		Weld, Rivet, Bolt, Inter connections

Figure I-6-10.
Major components "make or buy"

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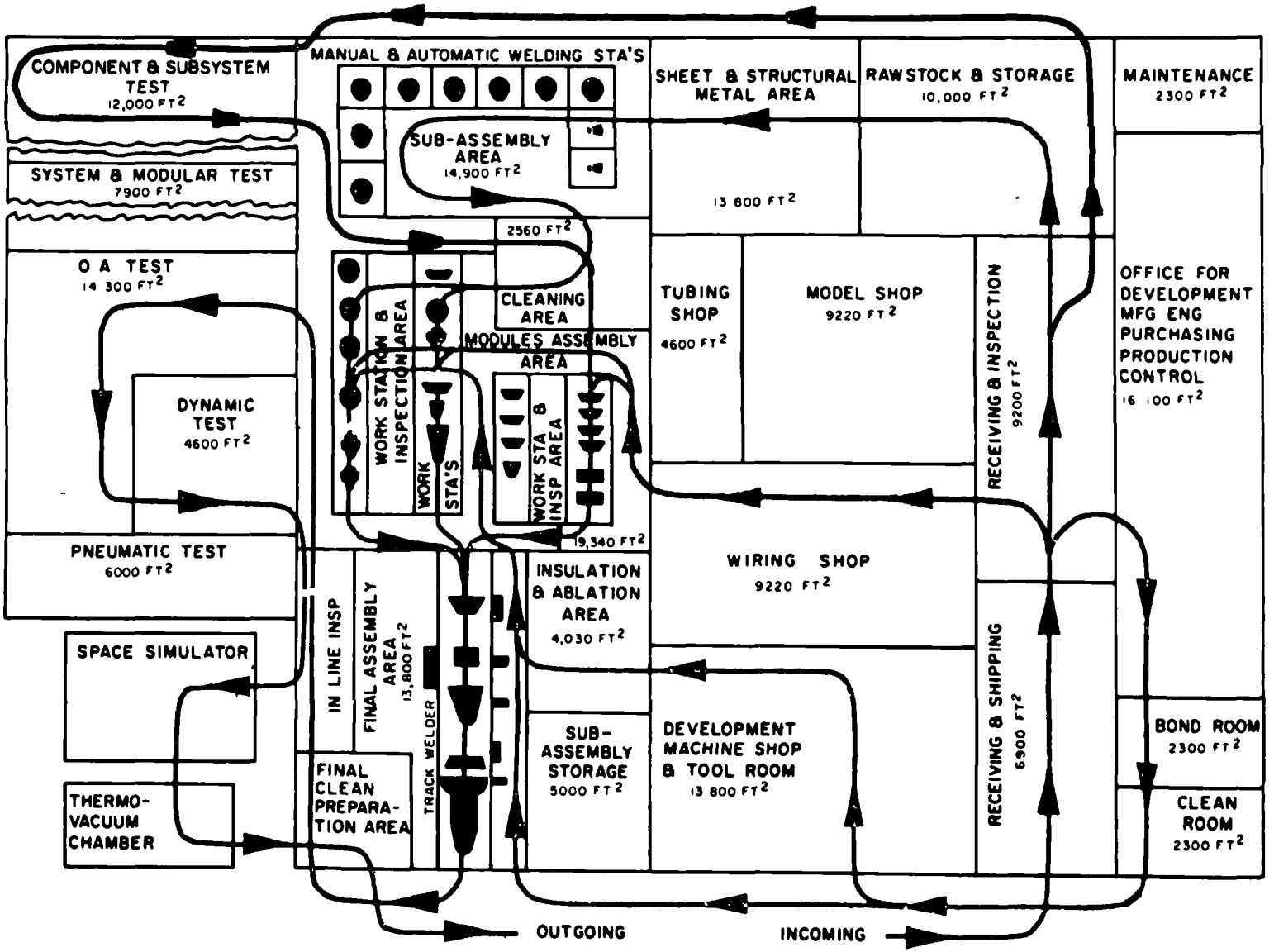

Figure I-6-11. Manufacturing floor plan for APOLLO

(a) Bond Room.

(b) Clean Room.

(c) Wiring Shop

4 Component/Subsystem Test Area.

Sheet metal and channels are cut and processed into proper configuration in the Sheet & Structural Metal Area where there are shears, saws, forming rolls, brakes, lathes, etc These forms are then moved to the Subassembly Areas where parts are fixtured and/or jigged for drilling, bolting, riveting and welding to form parts of the various modules Parts are then cleaned and inspected. Modules that require an ablation or temperature limiting coating will move to the Insulation and Ablation Coating Area. When the coating operations is complete, these parts will move to the Modules Assembly Area together with the other parts that do not require an ablation coating.

Stored subassemblies such as the mission module or outerfairings move into the fabricated assemblies Wiring, tubing, control and instrumentation modules, supporting channels, floors, bulkheads life support and all other equipment will be supplied, installed, and checked out along the various work stations. Mission Modules and Command Modules that have been fully assembled along this line are moved to Q C Areas for systems and acceptance tests. After parts have successfully completed the tests, they return to the Modules Assembly Area where the Mission Module and Command Modules are assembled into the outer Front Fairings.

The assembled Front Fairing with its Mission Module and Command Modules, the Cylindrical midsection and the Propulsion Modules move into the Final Assembly Area. A track welder is provided to make longitudinal or circumferential welds wherever necessary A track fixture helps to hold the parts for riveting, bolting or welding Optical alignment equipment along the line assures accurate assembly of the vehicle. The completed vehicle moves to Q. C. for final acceptance tests and the space simulator for flight certification testing. With the completion of final cleaning the APOLLO is then disassembled and prepared for shipment.

6.8 MANUFACTURING ENGINEERING

The MSVD Manufacturing Operation will provide technical support for the APOLLO program in matters pertaining to the producibility and manufacture of equipment. This will include:

1. Develop new manufacturing processes, equipment, techniques and capabilities dictated by the APOLLO system. In this regard MSVD will call upon the total manufacturing experience of the whole General Electric Company through direct contact with other departments and through the GE-Manufacturing Service Group in Schenectady, New York.
2. Work with engineering to ensure that APOLLO designs will permit the latest manufacturing techniques, and will reflect the greatest possible ease and economy of manufacture consistant with engineering requirements.
3. Monitor the manufacture of APOLLO equipment to be certain that the finished equipment is produced by acceptable techniques which will satisfy engineering requirements.
4. Support the reliability efforts described in Section 6.9 which pertain to manufacturing.
5. Develop tooling and fixtures on pre-prototype hardware and prove them out on trial manufacturing runs for follow-on APOLLO production.
6. Based upon the above activities prepare flow charts showing manufacturing sequence and work flow.

6.9 SHOP OPERATION

The Mock-up and Fabrications Shop will construct a mock-up of the APOLLO vehicles by means of which the designer's special visualization of the entire assembly will be checked and confirmed, to prevent any possibility of interference between adjacent components and to aid the routing of tubing and wiring. Mock-up and Fabrications will also make those sheet-metal parts that are to be fabricated "in-house", and will perform welding, heat-treating and painting operations.

The Machine Shop will perform machining operations on parts for the APOLLO project. Like the other shops, the Machine Shop is staffed and equipped to turn out work of the high degree of precision that is needed for APOLLO. A relatively recent acquisition in the Machine Shop is a tape-controlled turret drill While extensive automation is not economically feasible for R and D production, appreciable savings can be realized through the selective application of mechanized techniques, as in the use of this tool

The Machine Shop will operate under a Dispatch function which coordinates shop activities to adhere to the established schedules Dispatch will issue work orders to shops on IBM vouchers and accumulate shop costs through electronic data processing. This data enables the shop managers to measure and control the expenditure of funds

The Wire Harness will be made "in-house" in the Wiring Shop. This area is equipped to produce the full range of electronic devices required by the APOLLO vehicles, from miniature flight components to large consoles for ground installations.

The APOLLO vehicles will be completed in the Assembly Areas. In the Assembly Areas the components will be mounted in the structures, and the vehicle assembled. Extreme care will be taken to prevent damage to the APOLLO vehicle components. The precautions that will be exercised will include physical protection of the vehicle and proper handling methods and equipment.

6.10 PURCHASING

The Purchasing organization will procure the materials and services that MSVD will use in support of the APOLLO project. In doing so, Purchasing will draw upon its familiarity with the thousands of proven vendors with whom it has done business. Purchasing will call upon the broad knowledge and experience of the Company's Purchasing Services Group in New York City.

6.11 PRODUCTION CONTROL

The Production Control Operation will be responsible for materials management for the APOLLO program. This will include master planning, scheduling, ordering and expediting of all material necessary to manufacture and deliver APOLLO equipment.

Production Control activity for APOLLO will encompass inter-related paperwork systems utilized to disseminate program information, to initiate manufacturing activities, and to coordinate the manufacturing functions in support of the APOLLO program.

To accomplish these objectives, Production Control will utilize a Production Data Center for mechanized preparation and distribution of production paperwork. The paperwork cycles, systems, and reports for APOLLO are illustrated in Figure I-6-12. Through this control of schedules, paperwork systems, reports and management controls, the expenditure of manufacturing funds for the APOLLO program will be properly directed and effectively managed.

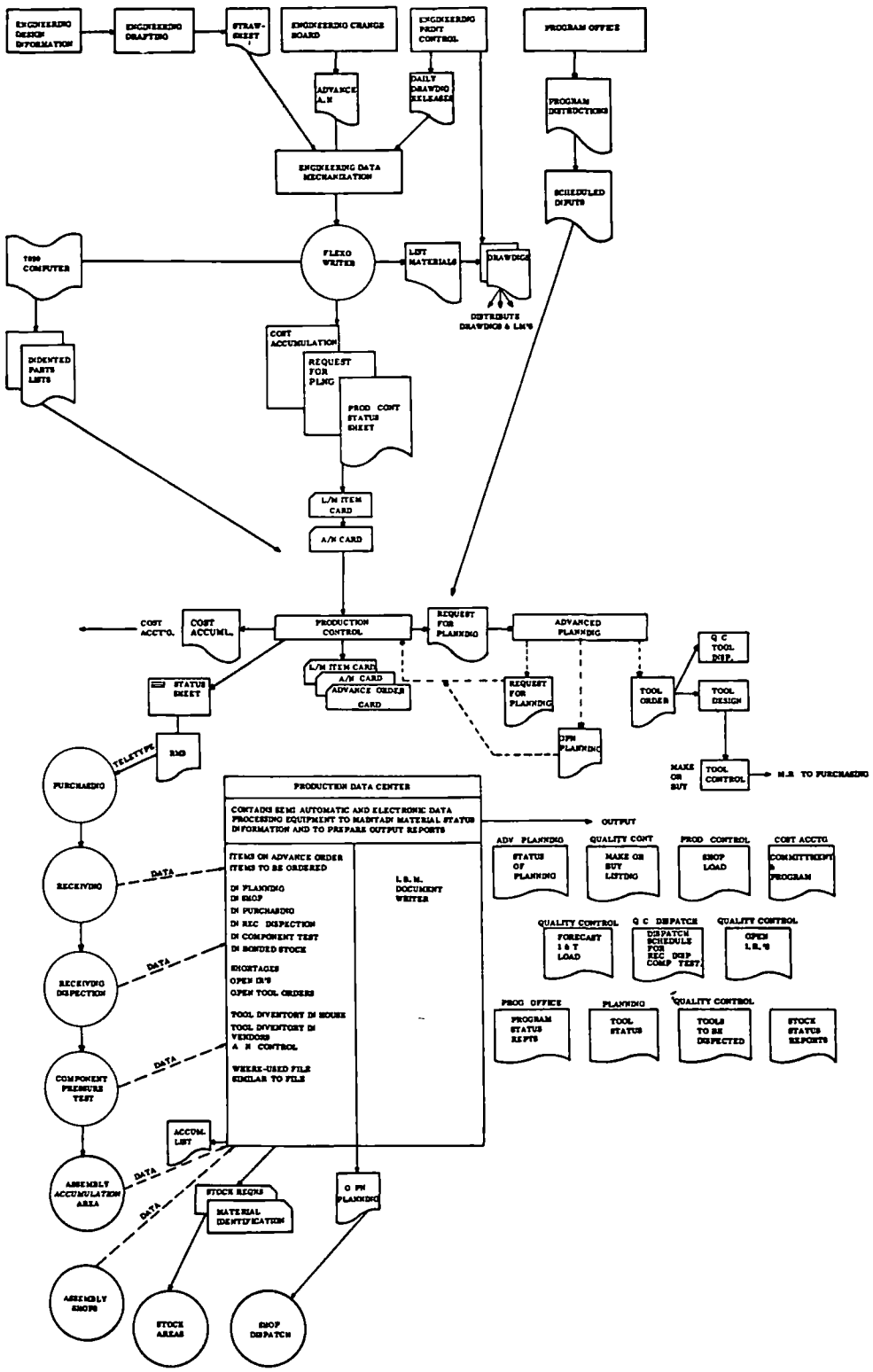

Figure I-6-12. APOLLO production control data flow

7.0 Quality Control Plans

7.1 GENERAL QUALITY CONTROL AND TEST PROGRAM

This section presents those functions which will be performed by the Quality Control and Test Operation on the APOLLO program. Accomplishment of these tasks will result in conformance of all equipment to drawings and specifications, and in insuring high quality workmanship and manufacture by MSVD, vendors, subcontractors, and co-contractors. These tasks will provide the following:

1. Conformance to design specifications of systems, modules, components and parts produced for delivery, flight test, and field evaluation by surveillance of manufacturing.
2. Field flight test operations of space vehicle ground support systems in accordance with NASA requirements.
3. The acquiring, reducing, and reporting of data resulting from all test activities.
4. Services to the engineering and manufacturing operations for technical, consulting and laboratory analyses in the fields of material characteristics and process capabilities.
5. Measurement standards and laboratory instrument services.
6. Computational services.
7. Environmental laboratory services.
8. Data to support the reliability program.
9. Surveillance of vendor quality control and test.
10. Acceptance testing.

The Quality Control activity will embrace all manufacturing activity from basic materials through the completed vehicle system Due to the magnitude of the program, subcontract vendor relationships will comprise a major area of effort The basis of this program is vendor education to the quality and performance requirements of his product. To as large an extent as possible, the vendor's Quality Control Systems will be utilized with regular audit-surveillance (without exception) by MSVD Quality Control Maximum utilization will be made of existing test facilities and state-of-the-art techniques to permit the APOLLO program to be accomplished in the minimum time at the lowest cost

The manufacture of hardware for the APOLLO program will be accomplished under the surveillance of the Quality Control and Test Operation using the following methods and techniques successfully employed on past and present programs The MSVD quality control organization is established to meet the quality control requirements of government specifications MIL-Q-9858 and MIL-Q-5923C (USAF).

7.2 RELIABILITY SUPPORT PLANS

7.2.1 Failure Reporting and Analysis

Failure reporting and analysis will be accomplished as described in Section 5.3.4 and 5 5 4 for all quality control tests Each failure must be analyzed in considerable detail It must be positively determined that the particular cause of failure cannot exist in the replacement part The problems associated with this proof are considerable, involving an integrated data system from material acceptance thru prelaunch countdown From start of program development testing through unmanned flight, all detected failure modes will be identified and positive action taken to assure non-recurrence

7.2.2 Parts and Materials Testing

Parts and Materials Testing will be accomplished as described in Sections 5 2 3, 5 4 1 and 5 5 Parts testing plans and material acceptance routines will be developed

consistent with critical characteristic identification, reliability requirements and vendor performance history.

7.2.3 Data Processing and Computation

Data Processing and computation will be accomplished to support the reliability tasks described in Section 5.2 as follows.

7.2 3 1 FAILURE RATE DETERMINATIONS

All operating data accumulated during the part manufacturer's acceptance tests and during all MSVD testing during equipment fabrication shall be stored and continually analyzed for resulting failure rate determinations

Data and information utilized for the determination of failure rates shall be in terms of quantity of failures, part description, load conditions and operating time in hours. The vendor data supplied for this determination shall consist of results from acceptance test and extended life tests results

Failure rates shall be determined at the following points·

1. Received Items – Indicating quality level of the parts received
2. After Screening – Indicating quality level manufacturing will receive.
3 After Fabrication but before Flight-Proofing – Indicating the quality level that the system will receive.

7.2.3 2 SCREENING TEST RESULTS

Specific variables resulting about the tests performed on the part design parameter contained in the screening test plan shall be accumulated on EDP cards and processed in the computer

Initial and subsequent electrical characteristic tests about a specified parameter shall be performed and the resulting variable measurement recorded – i e.,

composition resistors, initial resistance readings recorded and punched on the Resistor EDP card. The card shall be processed in the computer which will be programmed to provide the lot average ($\bar{x}$) for resistance and lot variability (σ) In addition, the readout shall also provide a ready breakdown of the specific number of resistors that correspond to a particular resistance reading. This in turn may be manually manipulated or forwarded to Data Processing and Computation for processing on the printer-plotter for defining the particular frequency distribution The distribution shall be analyzed for normality and a decision made to accept, reject or partial accept (This decision shall be made by Quality Systems Engineering in conjunction with Technical Requirements and Analysis and Engineering) A reject or partial accept decision will be forthcoming in the event that a bimodal or rectilinear distribution is evidenced The average ($\bar{x}$) and variability (σ) factors shall be compared to those found from results of the vendors production and acceptance tests. Analysis shall be performed to determine any significant differences which may be presented and resulting corrective measures which may be concerned with handling, transportation, packaging, test methods, etc. Following the specified screening test, the resistance will again be measured and the results punched on the Resistor, EDP card. However, the computer during this phase, and results from subsequent resistance measurements during the total test cycle, shall be programmed to provide a measure of the lot pattern behavior in terms of resistance drift before and after screening. This will be accomplished by providing a measure of $\Delta\bar{R}$ and σ, as well as the distribution Again the distribution shall be analyzed for obvious accept/reject decisions. The measure of σ, based on $\Delta\bar{R}$, shall be used for comparison to σ_ρ for determination of maximum allowable drift. The initial value of σ_ρ shall be provided by Technical Requirements and Analysis. The computer shall be programmed to provide a combined measure of σ, as additional lots are received and processed. Results from a minimum of five (5) lots shall be accumulated before estimating σ, of the population for the particular Resistor type. σ', shall be determined by assuming constant in-process variations for the particular part manufacturer and used for determination of maximum

allowable drift σ until an additional five (5) lots have been received whereby σ' shall be re-evaluated.

The above analysis will be performed on all other specified parameters of other part types in a like manner.

The results obtained from the samples submitted to Accelerated Life Test will have defined the behavior of the particular lot based on the relative position of the stress-life. In order to determine the behavior pattern for the individual parts contained within the lot, all parts shall be overstressed for a short period of time (minutes). Results from this proof test shall be used to describe the distribution and determine the acceptability of the parts. This shall be performed in a like manner as described previously.

7.2.3.3 ACCELERATED LIFE TESTS

Assuming the validity of exploratory tests during the determination of the initial stress-life relationship for a particular part type from the Engineering Tests Evaluation, a measure of subsequent lot behavior on future lot shipments shall be performed by subjecting a sample to accelerated life test. The technique used shall be that of submitting a sample lot of parts to a rapidly increasing stress which will identify the relative position of the stress-life curve for the part type as contained within the lot. The slope for the stress rise shall be determined from evaluations of the Engineering Tests. Results from this test shall be utilized in providing the measure of assurance needed in determining whether the life requirements for the particular lot have shifted radically. The data will also be utilized in performing correlation analysis about the variables obtained from accelerated and evaluation tests and evaluated for significance. All data shall be key-punched by Data Processing and Computation.

7.2.3.4 IN-PROCESS INSPECTIONS AND TEST

Results from vendor and in-house process findings shall be utilized in establishing control charts for troublesome attributes and/or variables. The vendor's process is defined to mean the production process for manufacturing a part whereas our in-house process is defined as the process which fabricates the part as a part. Information relative to cost or process average shall be utilized in determining the process quality levels. Two methods presently contemplated for use are:

1. Quality level = $\frac{\text{cost of finding failure*}}{\text{cost of not finding failure}}$

   *Failure in this case will not be defined as that which affects life.

2. Quality level = 1 - process average.

Techniques such as analysis of variance shall be utilized in determining significant shifts in production variables which in turn will test the assumptions made in estimating the variability of a population.

All failures from the in-process cycles shall be subjected to tear-down and the results analyzed in determining failure modes. These results shall also be utilized in preparing the various vendor performance reports.

Troublesome variables about specific design parameters shall be accumulated and processed by Quality Control and Test for resulting distributions and evaluations. Vendor supplied data of this nature shall be key-punched and processed as previously described.

7.2.3.5 COMPONENT TEST

Analysis of component test results is presently planned at accumulating variables data about troublesome part performance parameters for resulting distributions. The distributions shall be evaluated for normality, and significant dispersions shall be subject to correlation analysis of variance to data accumulated during parts testing. This shall be processed from data and information contained on the DCS data sheets and part EDP cards

All operating parts data during component test shall be key-punched on the part EDP card and forwarded to Data Processing and Computation to be processed for resultant failure rate determinations

7 2 3 6 SYSTEMS TEST

The analysis activity during this phase of testing shall be similar to that planned for Component Test described above.

7 2 3 7 FIELD TEST

All inspection and test results from the field will be accumulated on the DCS and corresponding data sheets Part EDP cards will be key-punched to include any accumulated test time on the parts This information will be processed by Data Processing and Computation for resultant failure rates.

In the event of any failure in the field, it is assumed that repair and retest shall be performed at MSVD-Philadelphia and that there will be no part replacements in the field Results obtained from the specific failures shall be analyzed to determine significant shifts in parameters The techniques and scope of the specific analysis shall be formulated upon receipt of the actual data In retrospect, the basic evaluations shall be similar to those planned for component test

7 2 3 8 VENDOR RATINGS

The vendor rating which has been in use reflects vendor performance in terms of percent defective from visual, mechanical and electrical characteristic inspections at incoming and test results from component test The finer increment of measure needed in evaluating vendor rating for Parts Vendors will be established by limiting the results about the parts level and redefining the classifications as follows:

1. Critical - Degradation Failure
2. Major
3. Minor - Visual defects

7.2 3 9 DEGRADATION FAILURE

A degradation failure is defined as a failure which is the result of some degree of change such that the measured parameter drifts out of tolerance Results used for the vendor rating shall be those which are found in the Parts and Components Evaluation Laboratory and reported on the Part EDP cards and DCS Processing for vendor ratings shall be performed by Business Data Processing

Other than that which is contained above, the rating shall be determined in the similar manner as is presently prepared

7.2.4 Engineering Test Evaluation

Results from the Engineering Evaluation Tests (See Figure I-7-1) will be analyzed to provide the following

1. Determination of the effectiveness of measurements during progressively stressing the part under load conditions and its relationship to ambient conditions for a resulting measurement technique to be used on acceptance and screening tests of production lots
2. Determination of the significance of measurements obtained in air as related to mounting conditions for resulting mounting conditions for production lots.
3 Determination of the significance of measurements obtained from environmental conditions as compared to ambient conditions for resulting test conditions for use on production lots.
4. Determination of the relationships between initial failure pattern and/or performance distribution from corresponding progressive stressing for the validity of proof tests and proof test loading conditions for use on production lots
5. Determination of effects of active storage on the part life characteristics.

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TOTAL QUANTITY / PART TYPE = 325 PARTS
STEP I SUBJECT ALL PARTS TO INITIAL SCREENING; i e , VISUAL INSPECTION, PERFORMANCE CHARACTERISTICS AND VIBRATION
STEP II SUB-DIVIDE PARTS INTO FOLLOWING

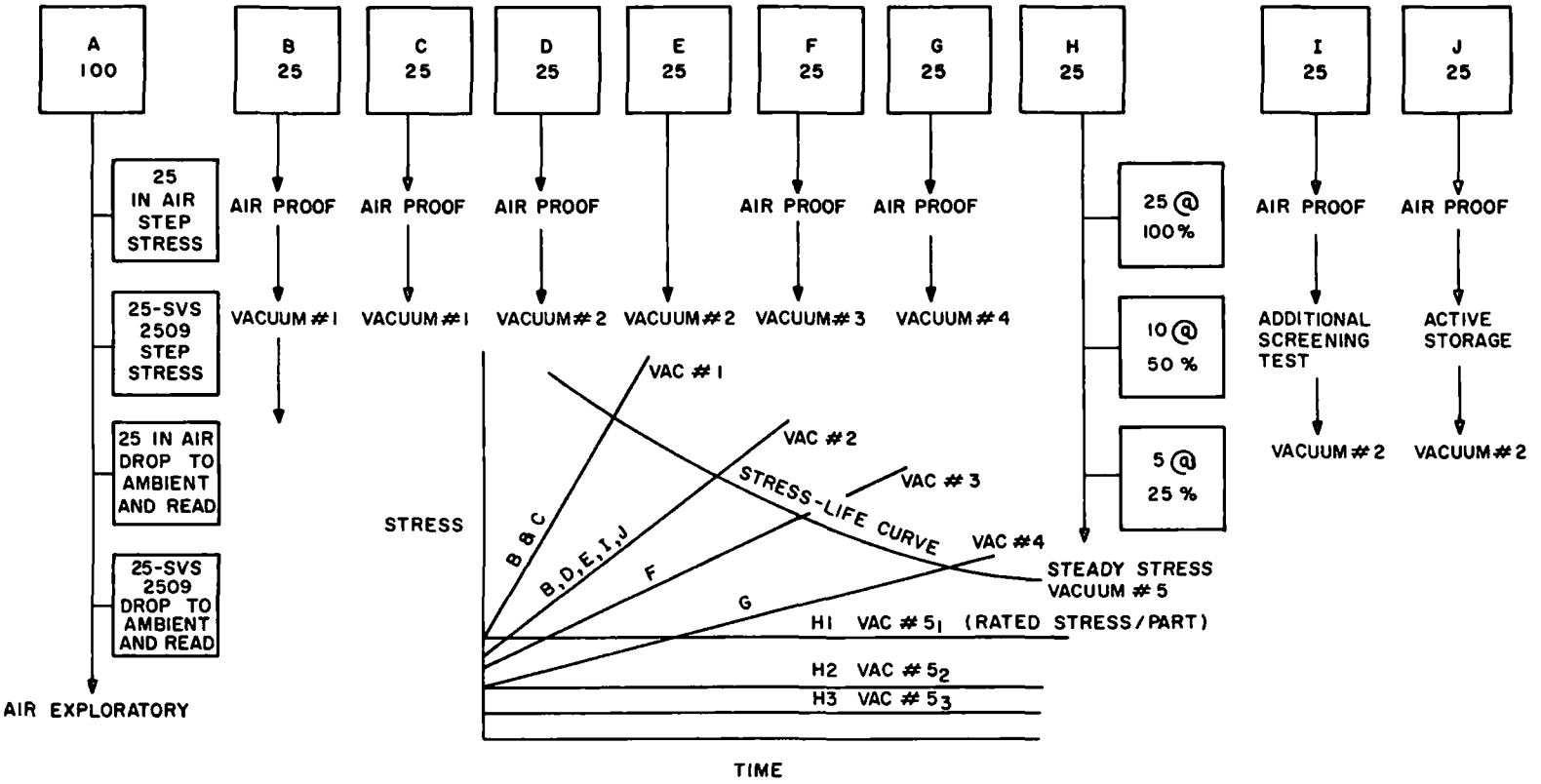

Figure I-7-1. Engineering test evaluation

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6. Determination of the validity of identifying the relative position of the stress-life curve from a single (rapid) progressive stress slope for resulting accelerated life test for use on production lots.

A base-measurement shall be identified by computing the average ($\bar{x}$) and variability (σ) values of the individual performance characteristics during the initial screening tests. The individual measurements shall be plotted to identify the distribution of the respective part performance characteristic The lot process average resulting from initial screening inspections and tests shall also be computed. The Process Average shall reflect that which is attributable to visual inspection results as compared to that which is attributable to performance characteristic test results.

The average ($\bar{x}$), variability (σ) and distributions shall be respectively computed and plotted for all measurements taken at the corresponding time intervals specified in the Test Plan. Each set of data shall be identified to the particular sample subgroups and test conditions All distributions shall be visually analyzed in determining the feasibility of statistical treatments.

The failure patterns shall be identified and plotted from the test to failure results obtained from sub-samples C, D, F and G to describe the stress-life curves for the individual part types. Results from sub-samples B, E, I and J shall also be plotted on overlays to indicate group dispersions. Results from H_1, H_2 and H_3 shall also be plotted to indicate end of life and relationships to the defined stress-life curve.

Determinations shall be arrived at by performing an analysis of variance study including such considerations as test for homogeneity (means and variances), test for comparison of mean effects, significance of interactions and factors involved. All mechanical processing of data shall be performed by Data Processing and Computation. The particular comparisons among sub-sample groups A through J and corresponding determinations A through F shall be as follows:

1 Comparisons about the air exploratory test results contained in A

2. Comparisons about test results from A, B, C, D, E.

3. Comparisons about test results from C, D, F and G.

4 Comparisons about test results from (J & D) and (I & E).

5. Comparisons about test results from B, C, D, E and H.

6. Various other comparisons deemed feasible from the test results.

7.3 QUALIFICATION TESTING

Quality Control and Test will perform qualification testing on components, subsystems and the system in accordance with the qualification requirements of the appropriate equipment specifications. For equipments tested by other testing agencies, Quality Control and Test will monitor the testing to assure that MSVD quality assurance standards are maintained Effective control will exist by virtue of Quality Control and Test representation on the Integrated Test Program Boards described in Section 5.3 2. The detail tests to be performed are given in Section 8.0.

7.4 ACCEPTANCE TESTS

Acceptance tests at MSVD are those tests performed on completed equipment in compliance with the applicable specifications preparatory to shipping the equipment to the customer. These tests, performed by the Quality Control and Test Operation, are categorized into the following Individual (100%) and Sampling Tests:

1. Individual (100%) Tests:

   a. Inspection Tests

   b. Functional Tests

   c. Flight Certification Tests

2. Sampling Tests

   a. Requalification Tests

7.4.1 Individual (100%) Tests

7.4.1.1 INSPECTION TESTS

Each component, subsystem, module and complete APOLLO system will be subjected to a visual inspection to insure that material, parts, physical dimensions, identification and workmanship are in accordance with the applicable specifications and drawings. This inspection will include all necessary measurements for continuity and resistance.

7.4.1.2 FUNCTIONAL TESTS

Each component, subsystem, module and complete APOLLO system will be subjected to functional tests. Inputs to the equipment will be varied over the ranges specified by the applicable specification and the outputs will be monitored for compliance with that specification. Where there is more than one input, each input will be varied individually through its range with the other inputs adjusted to the low end of their tolerance. All inputs will be tested in this manner to test for interference in all outputs. Equipments which do not lend themselves to testing as described above will be tested in a manner consistent with the nature of the equipment and will demonstrate that the functional requirements stated in the equipment specification are satisfied.

For the above functional tests and those functional tests performed in conjunction with environmental tests, MSVD will employ the Automatic Test Director and Analyzer (ATDA). The ATDA shown in Figure I-7-2 is an automatic equipment tester which permits high speed, simultaneous testing of complex systems and subsystems with economy of time and manpower, with great accuracy. Inputs are supplied in accordance with Standing Instructions defining the test procedure. The intelligence input is in the form of an English language input. Once the input is received, a

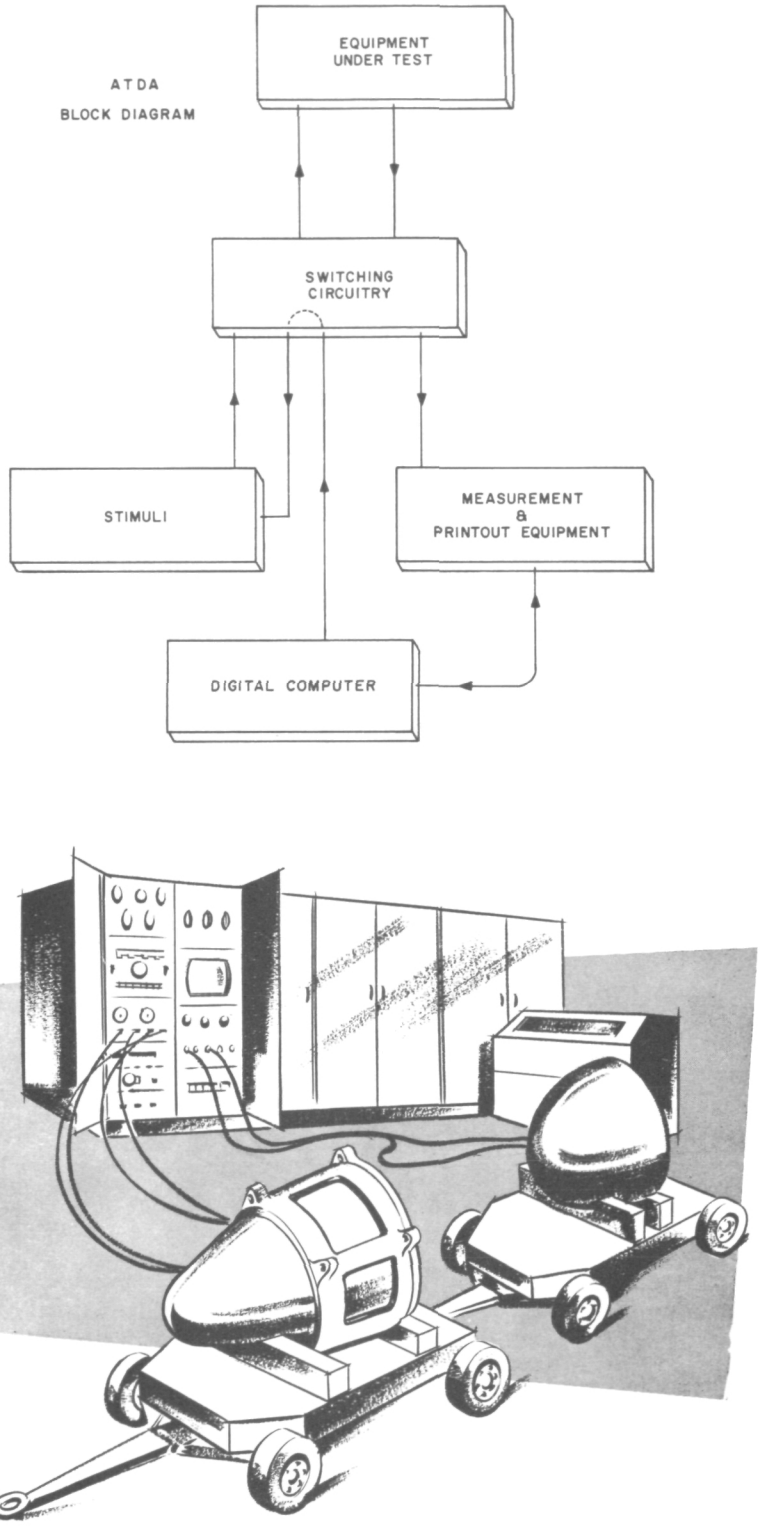

Figure I-7-2. Automatic test director and analyzer (ATDA)

manual transition of information from the English language input to the computer parameter format is accomplished. The inputs are then fed into the 7090 computer which, according to prearranged programs, produces the given output tapes to be utilized on the ATDA units in the conductance of tests. The output tapes will be used to prepare test listings and reports.

Figure I-7-3 shows the Integrated Universal Component Tester (IUTC) used to conduct automatic functional testing of components.

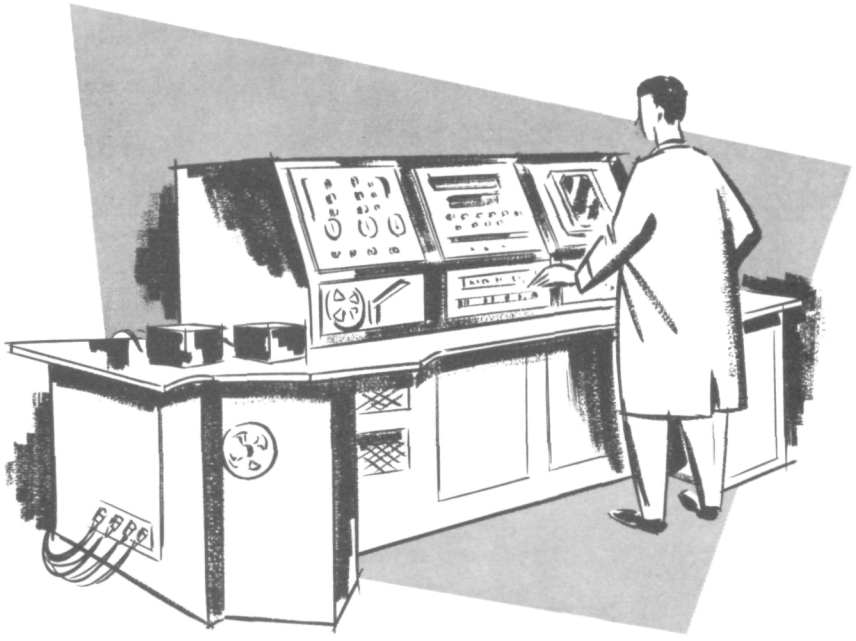

Figure I-7-3. Integrated universal component tester (IUTC)

7.4.1.2.1 Component Functional Tests

Based upon the MSVD preliminary design concept for the APOLLO system the functional tests of components will be based upon the following criteria:

1. Life Support Subsystem Components

   a. Solar Cells. Each solar cell will be tested for power output and response when subjected to a light source which simulates the sun's

spectrum for various intensities as required. Each cell which is acceptable shall be placed in bonded stock to be controlled for placement in a solar array. A Xenon solar source is now being fabricated for MSVD.

b. Solar Array and Reflector. The completed array shall be exposed to a simulated solar spectrum. The power output shall be measured under actual loads and various intensities as specified.

c. Battery (solar cell system). Each battery shall be given an insulation resistance and hypotential test. A lot check shall be made on a specified number of batteries. This test shall include a charging cycle, simulated load test with power output monitored during the functional tests in ambient and environments. A requirement shall be stipulated that prior to use in flight, a battery of any lot shall indicate charging ability, a short load test accompanied by a recharging cycle to prove its capability. An additional test on the lot samples shall be to use them in conjunction with the solar array tests in a simulated subsystem test.

d. Battery (Emergency). Here again, a check shall be made on a specified quantity of a lot. Insulation resistance and a hypotential test shall indicate quality of the dielectric on all batteries. The lot check batteries shall be functionally tested with simulated loads at specified environments. The flight batteries, if not thermal type, shall indicate charging ability and power capacity. Thermal types shall indicate squib continuity and resistance.

e. Instrument Panels and Consoles. Each instrument panel shall be given a rigid functional test with each control and monitoring unit operating and monitoring simulated flight conditions.

f. Sensing and Control. Each sensor shall be subjected to its own range of environments with its output transmitted to a simulated

monitoring system, or control system, to verify that the sensor will supply the correct output to indicate faithfully or control effectively whichever is required.

g. Oxygen supply (primary) test will include proper functioning of pressure regulators, leak test of tubing, and proper flow test of the system.

h. Oxygen supply (secondary) test on the secondary system will be identical to the primary system.

i. Diluent supply (primary and secondary) test will include pressure regulators, tubing, pressure leak test, and flow.

j. CO_2 removal normal test will include reactivation capability test, temperature rise, and valve and blower performance test.

k. Noxious and toxic removal system functional tests will consist of introducing samples of the test gases into a closed system and measuring the absorption rate with a mass spectrometer.

l. Water removal functional tests will consist of introducing water vapor into a closed recirculation system and measuring the amount of water absorbed by a mass spectrometer.

m. Heat exchanger (primary and secondary) functional tests will consist of subjecting the equipment to heat balance measurements and evaluating their ability to transmit the required heat flow.

n. Fire control system functional test will consist of subjecting the sensors to open flames and an evaluating of the system in extinguishing fires which produce their own oxygen for combustion and normal fires. Time required for complete extinguishing will be a mark of evaluation also. Test for reignition will be conducted with the subsequent system activation.

o. Particulate matter filters functional tests will consist of introducing dust particles of the required size into a closed recirculation system, and the rate or efficiency of filtration measured by use of a mass spectrometer.

2. Recovery Subsystem Components

a. Programmer. Each programmer will be tested for proper output functions when subjected to a simulated input and simulated load.

b. Power Supply. The power supply is composed mainly of batteries and will be tested as in paragraph 1c above.

c. Chaff ejection test will insure ejection of the necessary quantity of chaff.

d. Flare cluster ejection test will be run on this component to insure its operability.

e. Sofar bomb functional tests will be performed to insure that the bomb is ejected without hindrance.

f. The dye marker tests will be performed in our Manufacturing and Processes Laboratory to insure the correct solubility, dispersion, and light reflectively.

g. Flotation equipment. Flotation equipment will be tested for pressure leaks and to insure complete functioning of all flotation equipment.

h. Hand-operated equipment. Special tests will be arranged to insure the workability under the power available (one man) and to insure that these devices are completely functional.

3. Instrumentation and Communications Subsystem Components

a. Antenna. The performance test for all antennae shall be performed with each antenna located in a suitable location to avoid reflections from surrounding structures. The VSWR of the unit shall then be

checked-appropriate power at the specific frequency shall be applied to the antenna and the incident and reflected power measured.

b. Transmitters. The acceptance test for both the 400-mc and the 2000-mc transmitters shall include measurement of all parameters such as power output, frequency VSWR, etc. under load conditions. Also the output will be checked for spurious radiations to insure against interference to other electronic components in the system.

c. Receivers. The 2000-mc and 400-mc receivers will be tested for sensitivity, drift, etc. In order to test the susceptibility of the receivers to interference they will be subjected to signals at frequencies of the radiating electronic equipment in the vehicle and on the ground.

d. Decoder and Encoder. The performance of each decoder or encoder shall be checked for proper response to a complete range of simulated input signals.

e. Data Recorder. The performance of the data recorder will be checked for frequency response, gains, etc.

4. Guidance and Control Subsystem Components

a. Astrotracker. Each astrotracker shall be mounted on a two axis gimbal and tested for tracking accuracy using simulated stars during a simulated flight and also tested using actual stars.

b. IR Sensors. Each IR Sensor shall be tested for accuracy using an artificial horizon.

c. Radar Altimeter and Computer shall be tested at the module level.

d. Stable platform equipment will be supplied for a test to assure the performance of a stable platform within required limits. This will require a gimbaling system to impose upon the platform definite set orientations to which the platform's orientation can be compared.

7.4.1.2.2 Subsystem and Module Functional Tests

Based upon the MSVD preliminary design concept for the APOLLO system the following subsystem and module functional tests will be performed. Wherever possible the subsystems will be tested mounted in the appropriate module; i.e., Command Module, Mission Module or Propulsion Module. The ATDA described in Section 7.4.1.2 will be employed for these tests. These tests will include the component functional tests described in Section 7.4.1.2.1 with all subsystems interconnected as well as pneumatic leak tests and dynamic module tests. These tests will be performed closed-loop with crews operating the Command and Mission Modules. Each module will be given weight, center of gravity, and moment of inertia determination tests. In addition to the above, the following specific functional tests will be performed.

1. Command Module

   Functional tests of the following subsystems will be performed using the ATDA and GSE.

   a. Life Support Subsystem and Ecological tests

   b. Communications

   c. Instrumentation

   d. Guidance and Control

   e. Navigation

   f. Electrical Power and Distribution

   g. Recovery aids

   A pressure leak test and a stabilization simulation test will be performed.

2. Mission Module

   Functional tests of the following subsystems will be performed using the ATDA and GSE.

e. Continuity checks will be made on the recovery subsystem squib circuits. Operation of the location devices will be accomplished.

f. By means of the Dynamic Test Machine, a dynamic test of the guidance and control subsystem will be made using the ATDA. It will be checked for correct response in roll, pitch and yaw. Correlation of telemetry response will be obtained during this test. Simulation of one-shot devices such as squibs, rocket motors, etc. will be provided.

g. The crew will be used to perform closed-loop checks of the life support subsystem. This will include ecological tests and evaluation. The seats and displays will be checked by seat operation, i.e., energizing the display functions and operating the manual controls. These checks will include verification and calibration of the associated instrumentation. Such parameters as partial pressures of oxygen, nitrogen, carbon dioxide, trace gases and water vapor as well as cabin temperature and pressure will be measured and compared with the readings from the displays for calibration verification.

7.4.1.2.3 Complete System Functional Tests

Based upon the MSVD preliminary design concept for the APOLLO system the following system functional tests will be performed in the following sequence:

1. Cabled Systems Test

   This test will consist of electrically cabling together the three disassembled modules and performing a complete systems test. This will permit certain systems tests to be performed and monitored which cannot be accomplished on the assembled vehicle.

2. Assembled Systems Test

   The three modules will then be assembed into the complete vehicle and the same complete systems test will be repeated.

a. Life Support Subsystem and Ecological Tests

b. Communications

c. Instrumentation

d. Guidance and Control

e. Navigation

f. Electrical Power and Distribution

g. Rest Area - Crew Compatibility

3. Propulsion Module

Functional tests of Propulsion Module will be performed using the ADTA and GSE. These tests will include:

a. Static Firing tests

b. Cold gas operational tests

4. Subsystems

The following functional tests of subsystems will be performed with subsystem mounted in the module wherever possible; otherwise the subsystem will be tested separately.

a. The tracking and command subsystem will be checked by operating the C-Band beacon, minitrack beacon, command transciever, and optical tracking devices.

b. The communication subsystem data links will be checked by operation of the FM/FM data, voice and wide band links.

c. The data storage equipment will be checked by operation of the tape recorder and camera.

d. The power and distribution system will be given continuity and resistance measurements. Battery voltage and umbilical separation checks will be made.

3. Pressure Leak Detection Tests

Leak detection tests will be made on vehicle plumbing, tanks, regulators, valves, etc. as well as the hull, modules and bulkhead doors. The pressure in each independent pneumatic and hydraulic system will be monitored for a sufficient length of time to establish that the time leak rate is below minimum requirements. A helium tracer gas leak detector will be used to locate leaks using the mass spectrometer principle.

4. Compatibility Test

A compatibility test will then be performed with the space vehicle connected to the ground support equipment and functioning with space support equipment. The crew will be on-board.

5. Endurance and Ecological Test

An endurance test will be performed on the space vehicle simulating the functional-time mission profile. This will include a stabilization system test on the three axis simulator using a simulated celestial arrangement to test the complete navigation, guidance and control subsystem. The ecological test will be run simultaneously with the endurance test. It will be a closed-loop test with the crew on-board. The time duration of these tests will be selected such that the total endurance test time at MSVD and in the field will equal the maximum permissible operational mission time.

6. Dynamic Properties Determination Test

A dynamic properties determination test will be performed on a Dynamic Properties Machine (Figure I-7-4) which will evaluate the total weight of the vehicle, the location of the center of gravity, the geometric moments of inertia and the location of the principal axis or measurement of the products of inertia. This will be accomplished with the crew on-board.

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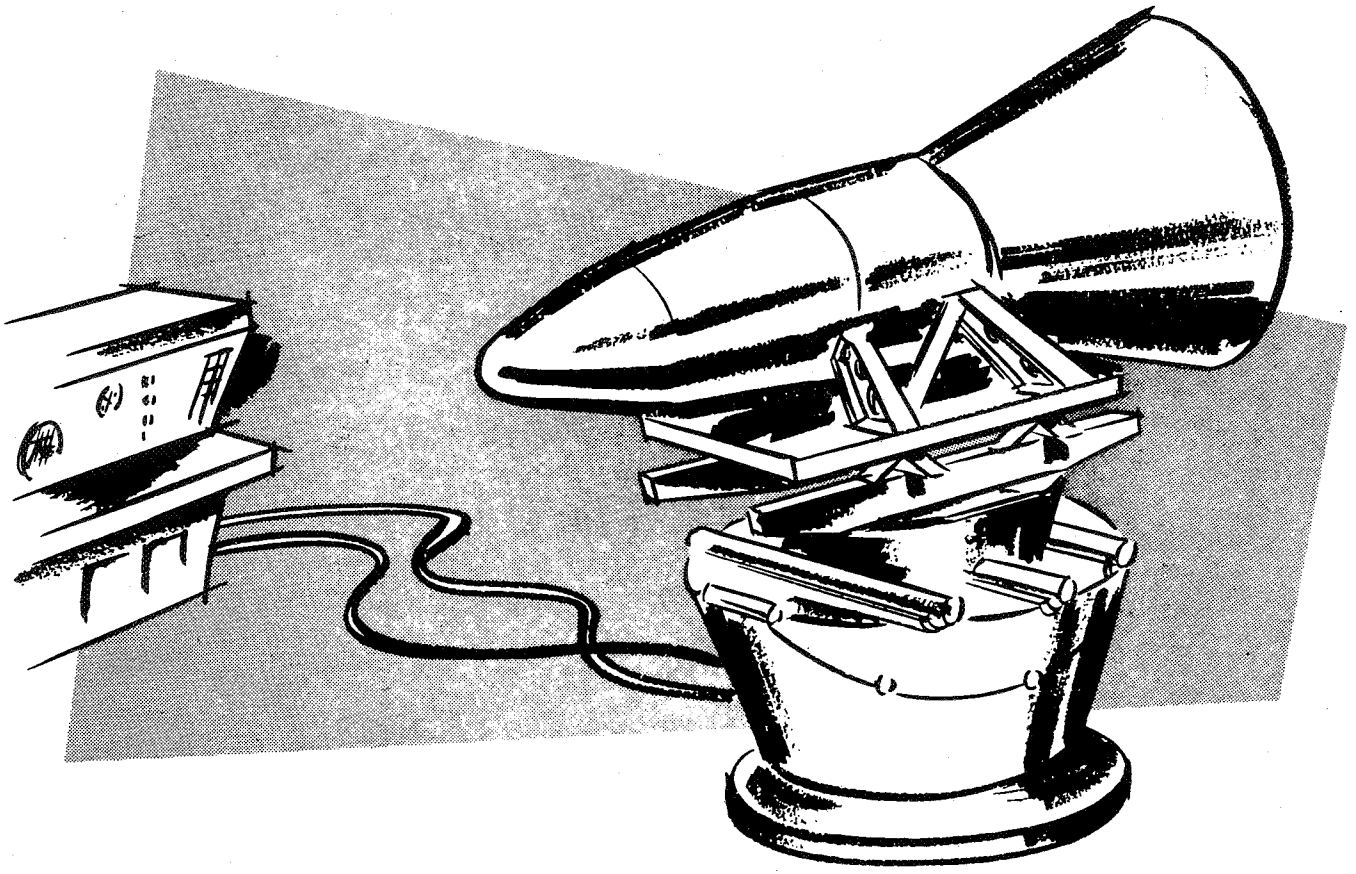

Figure I-7-4. Dynamic properties machine

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7.4.1.3 FLIGHT CERTIFICATION TESTS

Flight Certification tests of the complete APOLLO system are shown in Figure I-7-5. These tests consist of the complete system functional tests described in Section 7.4.1.2.3 and the module functional tests described in Section 7.4.1.2.2 performed in conjunction with the environments shown in Figure I-7-5. The functional tests will be conducted during, or before and after each environment to verify that no environmentally induced degradation has occurred. Spare parts will be mounted in the module and given flight certification tests before they are certified for use.

7.4.2 Sampling Tests

The individual tests described in the previous paragraph are non-destructive tests performed on each equipment to verify that the equipment meets the specification and drawing requirements. The sampling tests, however, are destructive tests performed on samples of manufactured equipment to verify that the equipment can perform satisfactorily under simulated operational mission environments for extended periods of time.

7.4.2.1 REQUALIFICATION TESTS

After successfully performing the individual tests described in Section 7.4.1, one equipment from a lot of ten equipments will be selected at random and be given a Requalification Test. Components, subsystems, modules and complete APOLLO systems will be requalified. The Requalification Test will be successfully completed before the rest of the lot is shipped from MSVD. The selected equipment will be representative of manufactured units. Any change in an equipment subsequent to the Requalification Test must be evaluated for a determination of whether the tests must be reaccomplished and if so whether in whole or in part. Where more than one source of supply is used for the equipment, the product from each source will be requalified even though the equipments are identical.

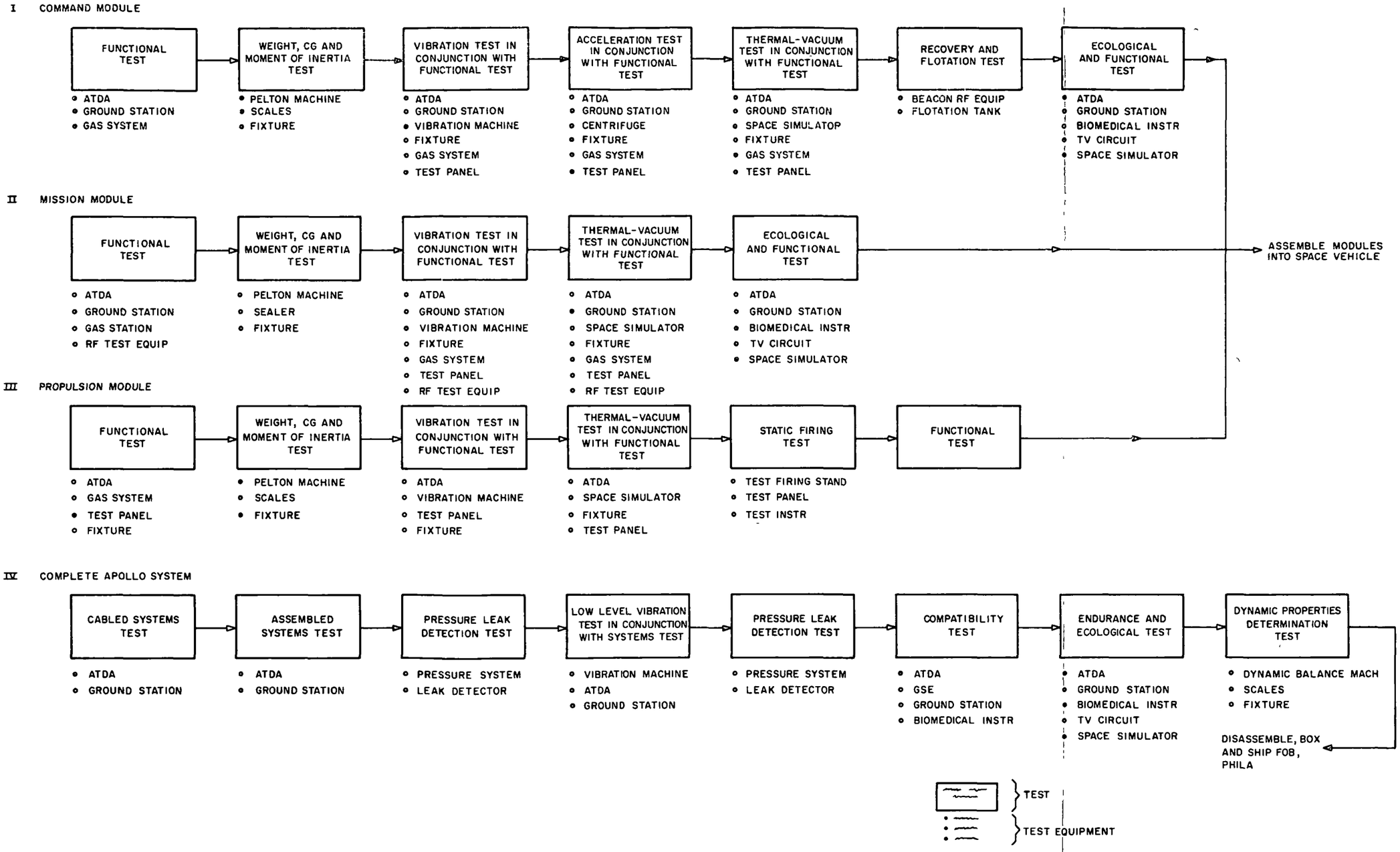


Figure I-7-5. Flight certification tests

The Requalification Test is identical with the design Qualification Test described in Section 7.3 and Section 8.0. It consists of functional tests performed while the equipment is subjected to simulated environments anticipated during the operational mission. In those cases where physical limitations prevent the functional test from being performed simultaneously with the environmental test, the functional tests will be performed before and after the environmental test and compared for equipment degradation.

Whereas the design Qualification Test is employed to qualify a design using equipment representative of forthcoming manufactured equipment, the Requalification Test is employed on production line equipment. The Requalification Test is employed for the following purposes:

1. To verify the continuing satisfactory performance of the engineering design.
2. To verify the manufacturing capability of a specific vendor to produce the design by specified methods and techniques.
3. To verify that a new vendor can satisfactorily produce the design by the specified methods and techniques.

7.5 MATERIALS AND PROCESSES

The Materials and Processes Engineering Operation will perform the following tasks:

1. Materials testing of raw materials used in house or by vendors at the time these materials are taken from stock from fabrication.
2. Certify all processes including operators conducting the processes both in-house and at vendors' plants.
3. Test and analyze process control samples.
4. Perform complete destructive testing of first piece fabrications and parts.

5. Establish all Materials and Processes specifications for the APOLLO program.

6. Establish contamination control procedures for the evaluation of assembly area cleanliness, freedom from dust and harmful atmospheric contaminants.

7. Review vendor process histories and conduct troubleshooting and certification activity in-house and at the vendor's plants.

8. Assist in vendor surveillance and in establishing the Vendor Performance Rating System in the area of materials and processes.

7.6 VENDOR QUALITY CONTROL SURVEILLANCE

7.6.1 Purchase Order Coding

All purchase orders to vendors or subcontractors will be coded for quality control provisions which must be met before the material, services, equipment, assemblies or parts will be accepted by MSVD. These provisions include the following:

1. Specify the degree of vendor facility survey by MSVD required to assure that the vendor quality control program is equal to MSVD standards. Such a facility survey will review the plant, machines, procedures, inspection and test equipment and records, and personnel involved in the manufacture and processing of material to be purchased.

2. Specify the type of inspection required by MSVD. When MSVD inspection-at-source is required, the vendor shall supply all necessary tools and equipment, and shall notify MSVD sufficiently in advance of the time when work will be ready, to allow an inspector to be present. When in-process inspection is required MSVD will inspect material at specific stages of the manufacture and test.

3. Specify the procedures, process certifications, production release samples, radiographs, process histories, raw material tests, control procedures, and operation certifications required for the supplied material or equipment.

4. Specify specific acceptance, qualification or requalification tests to be performed by the vendor. This will include failure and corrective action reporting using MSVD procedures.

5. Specify what federal, military or commercial specifications, standards, or drawings are applicable to the material or equipment to be supplied.

6. Specify unique Quality Assurance Provisions (QAP) required for a product.

7.6.2 MSVD Vendor Certification Program

MSVD will apply to APOLLO the Vendor Certification Program which is a continuous evaluation of vendor performance on MSVD contracts. This program audits a vendor on the following points:

1. Quality Control management controls.

2. Review of written procedures covering the control of quality.

3. Purchasing operation review.

4. Receiving and Receiving Inspection operation review.

5. In-process controls - fabrication and test and inspection.

6. Final controls - assembly and test and inspection.

7. Packing, packaging and shipping controls.

8. Special systems review.

9. Spot check vendor's products in our
   a. Receiving Inspection Area
   b. Systems Test Program
   c. Field Test Work
   d. Requalification Testing

10. Compile Quality Control data on vendor's products with a monthly summary from our IBM Data Processing Operation.

7.7 QUALITY CONTROL DURING MANUFACTURE

7.7.1 Receiving Inspection

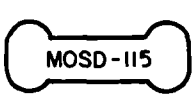
Receiving inspection will be conducted to accept incoming vendor material and equipment. These will be inspected as indicated by Quality Control Codes and/or Quality Control planning card, and tested as outlined on the test planning card. These cards will contain all necessary Quality Control information to insure acceptance per the contract.

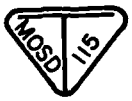
The Material and Process Laboratory will release results of tests conducted on incoming materials on a Laboratory report and Vendor's Quality Control card in the Receiving Section will record the number of these reports. All certifications and test results accompanying the material or equipment will be checked against quality control provisions.

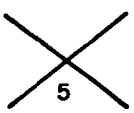
When inspection and testing have been completed, the accepted parts will be stamped and the material moved directly into stock.

7.7.2 Quality Control Stamps

Quality Control stamps will be used to indicate that material, parts and/or assemblies have been accepted, withheld, rejected or tested by Quality Control and Test personnel. The following stamps will be employed on APOLLO

Stamp #	Symbol	
1.		Preliminary Operation Approval Stamp This stamp indicates approval of a particular operation or group of operations on a part that requires additional manufacturing.
2.		Preliminary Test Stamp This stamp indicates approval of a test operation or group of test operations on a part that requires additional testing.

Stamp #	Symbol	Use
3.		Final Test Stamp This stamp indicates approval of parts or devices that require no additional testing before shipment.
4.		Dependent Final Test Stamp This stamp indicates part or device is acceptable as a dependent of an accepted lot and no additional testing is required before shipment. All parts or devices actually tested and approved will be marked with stamp #3, remainder of the lot with this dependent Final Test Stamp.
5.		Final Acceptance Stamp This stamp indicates final acceptance and is used where no additional testing and inspection is necessary.
6.		Dependent Final Acceptance Stamp This stamp indicates part or device is acceptable as a dependent of an unconditionally accepted lot and no additional testing and inspection is necessary. All parts actually tested and inspected will be marked with stamp #5, the remainder of the lot with this Dependent Final Acceptance Stamp.
7.		This stamp is used to indicate material or equipment was received for one or more of the applications

Stamp #	Symbol	Use
		1. Engineering Evaluation 2. Experimental Samples 3. Production and Shop Maintenance Where impression or ink stamping is impossible, material or equipment shall be identified by a red dot acid etched in lieu of stamp.
8.		Condemned Stamp This stamp is used when part, material, or devices are to be scrapped. It indicates that rework to drawing tolerances, or specification cannot be made.
9.		100% X-Ray Stamp This stamp indicates part is unconditionally radiographically acceptable.
10.		Percentage X-Ray Stamp Dependent portion of an unconditionally accepted lot.
11.		X-Ray Reject Stamp This stamp indicates part has been inspected and found radiographically unacceptable.
12.		100% Magnetic Particle Stamp This stamp indicates part is unconditionally acceptable by magnetic particle inspection.
13.		Percentage Magnetic Particle Stamp Dependent portion of an unconditionally accepted lot.

Stamp #	Symbol	Use
14.		Magnetic Particle Reject This stamp indicates part has been inspected by magnet particle technique and is unacceptable.
15.		Penetrant Stamp — 100% Stamp indicates part has been inspected 100% by penetrant technique and is unconditionally acceptable.
16.		Partial Penetrant Stamp Dependent portion of an unconditionally accepted lot.
17.		Penetrant Stamp — Reject Stamp indicates part has been inspected by penetrant technique and is unacceptable.
18.		Welding Acceptance Stamp (a) Where parts or assemblies are inspected for welding and accepted. (b) Whenever possible the stamp will be applied to an area which will not be covered at a later date. This may refer to paint or the further assembling of the part.
19.		Welders Operation Stamp (a) Utilized to indicate certified welder performing Welding Operations. (b) Whenever possible the stamp will be applied to an area which will not be covered at a later date. This may refer to paint or the further assembling of the part.

Stamp #	Symbol	Use
20.		Operability Assurance Stamp (Flight Certification) This stamp indicates acceptability of component after completion of Operability Assurance Testing Requirements.
21.		Pressure Test Stamp This stamp indicates acceptability of component after completion of Pressure Testing Requirements.
22.		Heat Treat Stamp This stamp indicates parts or material have been subjected to specified heat treating requirement.
23.		Hold for Material Review Board Stamp This stamp indicates that the part or material does not conform to applicable drawings or specifications and is to be submitted to the Materials Review Board for approval. Before parts or material bearing this stamp may be used, acceptance at MRB Stamp #24 must also be stamped on part or material.
24.		Acceptance by Material Review Board Stamp This stamp indicates that part or material does not conform to applicable drawings or specifications, but has been accepted through action of the Materials Review Board. This stamp cancels Stamp #23 when it is used in such a manner that its border interlocks the border of Stamp #23.

7.7.3 Equipment Control

All measuring equipment machines and gauges will be identified. All new equipment will be initially checked to insure the equipment conforms to equipment print or specification for which the equipment is intended. History cards will be kept on all equipment. These records will be used as a basis for determining frequency of periodic checking and calibration. The following classes of measuring equipment will be maintained and calibrated in accordance with established MSVD procedures:

Precision Gage Blocks
Electrolimit Gage Block Comparator
Standard Measuring Machine
Supermicrometer
Electrolimit External Comparators

Electrolimit Internal Comparators
Comparators
Optical Dividing Head
Index Head
Profilometer

Surface Roughness Comparator Blocks
Rockwell Hardness Tester
Brinell Hardness Tester

Superficial Hardness Testing Equipment
Optical Comparator

X-Ray Viewer
Thread Gaging

Thread Comparators
Thread Wires

Squares
Surface Plates
Optical Flats
Toolmakers Flat
Micrometer

Vernier Calipers
Vernier Depth Scales
Vernier Bevel Protractors
Vernier Height Gages
Transfer Measurement Equipment

Dial Indicators
Dial Bore Gages
Dial Groove Gages
Snap Gages
Toolmaker's Knees, Angle Irons, and Box Parallels

V-Blocks
Sine Bars, Blocks, Plates and Fixtures
Parallels
Plug Gages

Master Cylindrical Square	Simple Inspection Tools
	Torque Wrenches
	Standards

Primary and secondary standards used to calibrate measuring equipment, machines and gages shall have their calibration traceable to the National Bureau of Standards and evidence of this shall appear on file in the Instruments and Measurements Laboratory.

Where primary and secondary standards do not exist at GE-MSVD to calibrate equipment, an outside source shall be selected with this capability. This source shall have the standards traceable to the National Bureau of Standards. Records of these outside calibrations shall be maintained at GE-MSVD for reference.

7.7.4 Manufacturing Tooling

All production tools from or to which parts or assemblies are produced for APOLLO shall be inspected and accepted or rejected on the basis of their ability to produce acceptable, and when required, interchangeable parts under normal operating conditions. Records will be maintained on Test and Inspection Cards of all accepted, rejected and conditionally released tools. This procedure will cover all tools including templates, detail parts, tools, assembly jigs and fixtures.

7.7.5 In-Process Inspection and Test

In-process inspection and test will be accomplished during the manufacture of components, assemblies, subsystems and the complete vehicle to assure the quality of fabricated equipment and to perform inspection and test which cannot be accomplished physically on the assembled equipment.

A Quality Control Planning Card will be issued for each component, subassembly, and assembly specifying attributes to be inspected and listing special inspection tooling. The attributes will be designated in one of the following categories·

1. Critical - A defect that judgment and experience indicate could result in a hazardous or unsafe condition, or, a defect that could prevent performance of the mission of the item.

2. Major - A defect, other than critical, that could result in failure, or materially reduce the usability of the unit or product for its intended use.

3. Minor - A defect that does not materially reduce the usability of the product for its intended purpose, or is a departure from established standards having no significant bearing on the effective use or operation of the unit.

The Planning Card will indicate "stop points" for inspection of all operations completed since the previous "stop point". The equipment will be marked with the stamps described in Section 7.7.2 as inspection and test is accomplished.

7.7.6 Logbooks

Installation and History Logbooks will be maintained as follows for each system produced.

7.7.6.1 R & D INSTALLATION LOGBOOK

This logbook consists of complete records of the end product including detailed records of progressive stages of manufacturing, testing and assembly. This logbook will be shipped with every Vehicle to the field site. Inputs come from Quality Control, Reliability, R & D Logistics and the Field Site in the form of requirements defining the contents of the logbook. Quality Control will coordinate these requirements, document them in the form of Standing Instructions and Department Instructions and compile the Logbooks.

Each Installation Logbook shall contain, but not be limited to, the following information:

1. Index containing the identification and page numbers of each individual item in the Logbook.
2. List of Hardware which shall contain the identification and weight of all non-data sheet items (cables, structures, etc.).
3. "In-Process" Test Data indicating locations and depths of sensors, special shield characteristics, etc.
4. Acceptance Test Data for component, subsystem, and system level testing. Vendor data shall be included for those component Operability Assurance (O/A) tests conducted by the Vendor.
5. Calculation results for weight and balance, and moments and products of inertia.
6. Significant Event Sheets indicating significant items encountered during test and inspection activities.
7. Quality Control Travel Tags indicating applicable test specifications and planned points and verification of test and inspection activities.
8. Special Engineering Procedures (S. E. P. 's) indicating changes in test procedures or defined limits of acceptance of those specific values out of specification limits.
9. Unit Discrepancies (Deviations and Variations) in the form of Inspection Reports (I. R. 's), material Disposition Board Reports (M. D. B. 's) and Unit Change Instructions (U. C. I. 's). A list of Alteration Notice numbers shall be included in each Logbook, however, the actual A. N. 's shall accompany the applicable drawings when shipped from GE-MSVD.
10. List of Shortages indicating those items not installed at the time of unit shipment.

7.7.6.2 R & D HISTORY LOGBOOK

R&D History Logbooks are copies of the original installation logbooks undated by the test results recorded at the field site. These books are put together and copies are provided to the Customer and Quality Control Document Control Office,

(where they are made available to all on a "Need to Know" basis) and to the appropriate Field Site.

7.7.7 Discrepant Material

Discrepant material discovered by inspection or test will be designated for rework, scrapped or referred to a Material Board for disposition using Inspection Reports (I. R.) as follows:

1. If the material is obviously unfit for use and beyond repair, it will be scrapped.
2. If the material does not meet requirements because of incomplete fabrication and can be completed, or, if complete but not in accordance with the specification and/or drawing, and can be reworked to agree with the drawing in all respects, it will be returned to the responsible Production Operation so that they may initiate action to bring the material within the specified requirements.
3. If a clear-cut decision cannot be made to scrap or rework the material, it will be referred to the Material Review Board (MRB) or the Materials Disposition Board (MDB) for action. These boards are made up of representatives of the Quality Control, Engineering, and Projects Operations with customer representation on the MRB. The MRB acts on equipment to be delivered to the customer. The MDB acts on R & D equipment to remain at MSVD for engineering test, evaluation, etc.

Discrepancies will be recorded, reviewed and analyzed to prevent repetitive manufacturing deviations or variations from established standards or equipment specifications.

8.0 Integrated Test and Evaluation Program Plan

8.1 GENERAL PLAN

The Integrated Test and Evaluation Program for Project APOLLO has been designed to assure complete and successful accomplishment of the project objectives. The immediate goal is to accomplish earth and lunar orbit and safe return to earth of a manned space vehicle. However, the program is designed to smoothly and naturally lead into the further goal of lunar landing and earth-return capability. The plan encompasses development, ground qualification, and acceptance tests of materials, components, subsystems, modules and the space vehicle/earth support system. Finally, the plan calls for accomplishment of unmanned and manned earth orbital, cislunar, circumlunar and lunar orbital flight tests.

In order to set a goal for the test program, and thus the design program, the system qualification requirements must be defined. This is accomplished by integrating the NASA requirements, all requirements as established by Systems Engineering and Quality Control concepts and the independent Test Integration and Reliability Engineering philosophy into a complete document, appropriately entitled "Systems Qualifications Requirements Specification." This document becomes the rule book in preparation of all system detailed test plans, a guide to the designer and the basis for all considerations of qualification buy-off by the MSVD Systems Integrated Test Program Board. This board is composed of representatives of the Engineering, Quality Control, and Manufacturing Operations and is chaired by the Test Integration and Reliability Engineer, a direct representative of the Program Manager.

Component qualifications is handled in much the same manner. Specifications for each component are prepared by the component design Engineer and must be approved by a board similar in makeup to the Systems Integrated Test Program Board and chaired by the Reliability Operation member.

One excellent means of determining the environments to which a component or system will be qualified is the preparation of a matrix which plots the regimes of operation, from factory to completion of mission, against the complete list of integrated environments. Such a basic matrix is shown in Figure I-8-1. This matrix would be expanded to the point where the level of quantitative definition of the environment would be substituted for the simple "x" where applicable.

From this matrix, another matrix may be prepared for each component or system for determining the worst possible levels of environment to which a component or system must be subjected. It can also be used for determining if combined environmental tests should be conducted for more realistic qualification and establishment of a higher level of confidence and reliability. A sample matrix of this nature is shown in Figure I-8-2.

Acceptance Tests will be conducted on all parts, components and systems. These tests are the responsibility of the Quality Control operation. In addition, to vendor and in-house surveillance on all parts, functional tests and mechanical inspection of these parts is performed on each and every item. The only exceptions are expendable items such as explosives where a lot sampling test technique is employed.

Qualification of production prototype hardware will be accomplished prior to manned flight. In addition, each production vehicle will be subjected to flight certification tests prior to shipment from the production facilities. This series of tests (sometimes called operability assurance tests) is conducted to affirm that the production vehicles will indeed function in flight. The tests are of a functional nature under selected environments at or near flight levels. In addition, those environments of other than the flight regimes considered critical to complete mission success are imposed. An example of these would be flotation of the command module as a consideration for water landings.

ENVIRONMENTAL	TRANSPORTATION	STORAGE	HANDLING & ASSY	PRE FLIGHT	POWERED FLIGHT	BALLISTIC	EARTH ORBIT	CISLUNAR	CIRCUMLUNAR	LUNAR ORBIT	RE-ENTRY	RECOVERY	POST FLIGHT HANDLING
SHOCK	X		X		X						X	X	X
VIBRATION	X		X		X								
TEMPERATURE	X	X	X	X	X		X	X	X	X	X	X	X
THERMAL SHOCK							X	X	X	X	X		
HUMIDITY	X	X	X	X	X						X	X	X
ACCELERATION					X						X	X	
VACUUM					X	X	X	X	X	X	X		
ACOUSTIC NOISE					X						X		
SOLAR RADIATION						X	X	X	X	X			
METEOROID IMPACT						X	X	X	X	X			
SAND & DUST	X	X		X								X	X
SALT SPRAY	X	X		X								X	X
FUNGUS	X	X										X	
BIRDS & INSECTS	X	X		X								X	X

Figure I-8-1. Matrix of environments and flight regimes

COMPONENT / ENVIRONMENT	SHOCK	VIBRATION	TEMPERATURE	THERMAL SHOCK	HUMIDITY	ACCELERATION	VACUUM	ACOUSTIC NOISE	SOLAR RADIATION	METEOROID IMPACT	SAND & DUST	SALT SPRAY	FUNGUS	BIRDS & INSECTS
IR SENSOR	X	X	X	X		X	X	X	X			X		
ASTRO TRACKER	X	X	X	X		X	X	X	X			X	X	
RECOVERY PROGRAMMER	X	X	X	X		X	X	X	X					
ANTENNAE	X	X	X	X	X	X	X	X	X	X	X	X	X	X
PARACHUTES	X	X	X	X	X	X	X	X	X					
RECOVERY BEACON	X	X	X	X		X		X	X					
G & C COMPUTER	X	X	X	X		X	X	X	X	X				
LIQUID O_2 CONVERTER	X	X	X	X			X	X	X					

Figure I-8-2. Sample matrix of environments and components or systems

8.2 PREMISES

This plan is formulated on the basis of the following premises:

8.2.1 Personnel safety and mission accomplishment is of paramount importance.

8.2.2 Ultimate objectives of the project are to be achieved at the earlist time, consistent with assured personnel safety and cost limitations.

8.2.3 Results of all tests will be evaluated and fed back, as advisable, to improve the design. This is a basic tenet of the reliability program.

8.2.4 To minimize program cost and to assure the early achievement of the ultimate objective, results of pertinent programs (such as Mercury, Atlas, Atlas-Agena, Centaur, Titan, Dyna Soar, X-15, etc.) will be utilized, and in addition, it is planned that where feasible, such programs will be used to accomplish specific test objectives of the APOLLO Program.

8.2.5 For the same reasons as in 2. above, maximum utilization will be made of existing test facilities and state-of-the-art techniques.

8.3 TEST PHILOSOPHY

Since personnel safety and mission accomplishment are considered to be of paramount importance, a thorough, comprehensive ground and flight test and evaluation program will be conducted prior to manned flights to assure the capability of the overall system to meet performance requirements with the utmost reliability.

The integrated test and evaluation program is divided into two sections:

8.3.1 The ground test program will consist of Preliminary Design and Development tests, Prototype Development and Qualification tests and finally Production Prototype Qualification tests.

8.3.2 The flight test program will consist of Development Flight tests and APOLLO-Saturn Flight tests.

8.3.3 The schedules for the test programs have already been presented in Section 2.0 of this volume but will be re-presented here, as needed, for convenience and clarity.

8.4 GROUND TESTS

8.4.1 Preliminary Design and Development

Initial design is based on analyses using previously obtained data and/or assumptions. This premise is acceptable for basic design concepts. However, detail final design often requires additional data to crystallize the assumptions used. Thus the test program must supply information for use in design as well as serve the purpose of evaluating and qualifying the design for operational use. This is the basic purpose of the Preliminary Design and Development Phase.

Vehicle design, life support, communications and instrumentation, navigation, guidance and control and electrical power supply development tests will be conducted. These tests will include, but not be limited to, such items as large diameter shaped charged explosives for separation, pyrolytic graphite ablation, star and sun trackers development and miniaturization, and liquid oxygen converter development for life support. In addition, configuration optimization tests using wind and shock tunnels, static tests of vehicle access pressure ports, free fall drop tests to determine impact and flotation characteristics tests will be conducted.

The matrix, Figure I-8-4 lists the programmed tests, hardware and facilities. Reference is here made to the Preliminary Design Ground Tests Schedule, in Section 2.0 of this volume.

8.4.2 Prototype-Development and Qualification Tests

Component and subsystem development tests will be conducted on breadboard and/or prototype hardware to develop and evaluate the design of the APOLLO Space Vehicle and associated ground support equipment.

Special development tests such as static firings of the on-board propulsion will be conducted on the propulsion, separation, etc., subsystems. The life support subsystems will be subjected to special space simulation development tests. The structures will be subjected to a series of load tests. The recovery subsystem will be subjected to high altitude land and water drop tests and set out tests to develop the subsystem and check range compatibility.

The general purpose analog and digital simulation computers within MSVD will be used for testing system concepts. Initially each computer will be used independently to handle problems for which each is best suited. Ultimately the digital and analog computers will be combined to simulate performance of the complete guidance and control systems, for example, under three and six degrees of freedom motion flight simulation.

The dynamics of the vehicle with rotation about the C. G. will be programmed on the analog computer, while equations associated with translation of the C. G. will be programmed on the digital computer. Attitude control hardware will be simulated on the analog computer. Vehicle computer intelligence will be simulated on the digital computer.

As breadboard and prototype hardware becomes available, it will be substituted for test equipment in the simulated system. Ultimately the entire control system will operate with actual prototype hardware. The three degree of freedom motion simulator at MSVD will be utilized in conjunction with the actual hardware control system for testing of the attitude control system.

The use of the Space Simulator and computer/sub-system substitution to project system testing permits an early start and the continuous and well-integrated development towards solving difficult problems.

Special prototype subassemblies such as guidance and control, communication, life support, power supply, etc., at the completion of the initial development tests, will be subjected to selected environments required to qualify the subassemblies for development flights.

Two partial and one complete APOLLO systems will be development tested and qualified for development flights as delineated in Section 2.0., Figure I-2-1.

8.4.2.1 COMMAND MODULE #1 (CM #1)

The CM #1 will be development and functionally tested and the subsystem and ground support equipment compatibility checked. At the completion of the development, functional and compatibility tests the CM #1 will be subjected to selected environment tests such as acceleration, vibration, temperature, vacuum, etc. at loads higher than mission levels to qualify the unit for development flights.

8.4.2.2 COMMAND MODULE #2 + MISSION MODULE #1 (CM #2 + MM #1)

The MM #1 will be development tested and the CM #2 + MM #1 will be functionally tested. Compatibility of the subsystems and GSE will be checked.

Special tests such as seal tests, customer furnished equipment compatibility initial acceptance test checkout, etc., will be performed using the CM #2 + MM #1.

Upon the completion of the special tests, the CM #2 + MM #1 will be used for crew training.

8.4.2.3 COMMAND MODULE #3 + MISSION MODULE #2 + PROPULSION MODULE #1 (CM #3 MM #2 + PM #1 - COMPLETE SYSTEM)

The PM #1 will be development tested.

The complete system (CM #3 + MM #2 + PM #1) will be functionally tested and checked for compatibility between subsystems and GSE. The complete system will be subjected to selected environments such as acceleration, vibration, space simulation, etc. at loads higher than mission levels to qualify the system for development flight tests.

The matrix for this phase of ground testing is shown in Figure I-8-5.

8.4.3 Production Prototype Qualification Tests

This phase of the test program will be conducted, after development of the design, on flight quality hardware and associated GSE. It will consist of a ground qualification test program at the component and system level as well as data from the flight qualification tests of components, subsystems and systems in the prototype development and qualification tests. In addition, component, subsystem and system flight certification tests will be conducted on production flight hardware.

The ground qualification program will include: (1) functional and compatibility tests at laboratory ambient conditions; (2) environmental tests at stress levels greater than worse case conditions to be encountered in the mission profiles: and (3) special tests as required. The ground qualification program will be conducted on a minimum of 3 each components and 2 complete APOLLO systems.

Flight certification acceptance tests will be conducted on every item of production hardware and will include. (1) inspection, (2) functional and compatibility tests, and (3) selected environmental tests of the flight system at stress levels at or near those encountered in flight.

Upon satisfactory completion of this phase, the hardware system design will have been ground qualified. In addition, acceptability of all delivery components,

subsystems and systems will have been assured. The flight certification procedures will be continued for all flight hardware produced and delivered.

The matrix for this phase of ground testing is shown in Figure I-8-6.

8.5 DEVELOPMENT FLIGHT TESTS

A series of flights is planned which will take advantage of existing programs being sponsored by the NASA. Much valuable data and experience will be gained for Project APOLLO by flying equipment and instrumentation on such programs as Mercury, Ranger, OAO, OGO, Atlas-Agena, Centaur, Titan, Saturn and others. Also, a program for proving out the APOLLO abort system from pad abort and abort at maximum dynamic pressure conditions is scheduled. For this purpose a special booster will be developed and used as was Little Joe for the Mercury Program. Figure I-2-6 definitizes this program as to the NASA projects and/or boosters to be employed, items of APOLLO hardware to be flown, regime of flight to be considered and purpose of flight. Also shown are schedules for these flights which are compatible with the NASA programs.

Subsystems such as guidance and control, communications, crew support, etc., together with "boiler plate" hardware simulating correct weight and CG of the actual space vehicle will be development tested and flight qualified on standard boosters. Compatibility of range interfaces with the various subsystem will be checked during these flights.

It should be noted that included in this series of flight programs are tests to determine the effects of weightlessness on various equipments planned for use in Project APOLLO. This is in addition to personnel testing in KC-135 Keplerian trajectory flights as part of crew training and water tank submersion weightless effect in the ground test program and crew training area.

Planned also during this phase are the extremely important programs of hyper-velocity re-entry to define the environment of re-entry at escape velocities and the

flying wind tunnel program to provide valid aero-thermodyamic configuration data. These programs must be accomplished either as part of Project APOLLO or as separate projects in order to make lunar flights feasible.

8.6 APOLLO-SATURN FLIGHT TESTS

Flight quality APOLLO vehicle command modules will be development tested and flight qualified by two ballistic flights using the Saturn development boosters. Two flight quality instrumented APOLLO systems will be development tested and flight qualified in a ballistic flight, one using the development Saturn C-1 booster and the other an operational Saturn C-1 booster. A third ballistic flight to extremely high altitude will be made to achieve high re-entry velocity.

A sub-orbital abort flight will be conducted to verify abort capability from this flight regime.

The final flights of this development and qualification flight phase will be four earth orbit flights of the complete APOLLO system using operational Saturn C-1 boosters.

The first two flights will be with instrumented APOLLO systems and the latter two will be instrumented systems with animals.

The final phase of the APOLLO-Saturn test program is a series of nineteen manned and unmanned flights using ground and flight qualified APOLLO vehicles and operational Saturn C-1 and development and operational Saturn C-2 boosters. As shown in Figure I-8-3, the flight definition figure, these flights progress from circular earth orbit to elliptical earth orbit to cislunar to circumlunar to lunar orbit in a logical sequence of proving out the men and equipment capable of taking each next step. Thus, a high level of confidence will be established prior to each next flight.

Acceleration, deceleration, re-entry heating, powered-flight loads and landing loads (impact) may be obtained from all the development prototype APOLLO

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FLIGHT NO	BOOSTER	VEHICLE DESCRIPTION	MANNED VS UNMAN	FLIGHT REGIME	PURPOSE
1, 2	C-1 (D)	DEV COMMAND MODULE	UM	BALLISTIC	INSTRUMENTED RE-ENTRY ENVIRONMENT, RECOVERY SYSTEM
3,4	C-1 (D)	DEV VEHICLE DEVELOPMENT SYSTEMS	UM	BALLISTIC	INSTRUMENTED COMM AND TRACK-RE-ENTRY ENVIRONMENT, SYSTEM, RECOVERY SYSTEM, LIFE SUPT SYSTEM
5	C-1	DEV VEHICLE DEVELOPMENT SYSTEMS	UM	ABORT-POWERED FLIGHT	INSTRUMENTED, SUB-ORBITAL VELOCITY ESCAPE AND RETURN
6	C-1	DEV VEHICLE DEVELOPMENT SYSTEMS	UM	BALLISTIC-HIGH ALTITUDE	INSTRUMENTED HIGH VELOCITY RE-ENTRY ENVIRONMENT AND RETURN
7,8	C-1	DEV VEHICLE DEVELOPMENT SYSTEMS	UM	EARTH ORBIT-CIR	INSTRUMENTED COMPLETE SYSTEM CHECK OUT LIFE SUPPORT POWER SUPPLY G AND C
9	C-1	PROD VEHICLE	UM	EARTH ORBIT-CIR	FLIGHT QUALIFICATION LIFE SUPPORT (ANIMAL)
10	C-2 (D)	DEV VEHICLE DEVELOPMENT SYSTEMS	UM	EARTH ORBIT ELLIP 25,000 MI	INSTRUMENTED RADIATION ENVIRONMENT G AND C COMM AND TRACK SATURN C-2 COMPATABILITY
11,12	C-1	PROD VEHICLE	M	EARTH ORBIT-CIR	FIRST MANNED FLIGHT SHORT DURATION MAN PERFORMANCE
13,14	C-1	PROD VEHICLE	M	EARTH ORBIT-CIR	HABITATION-1 WEEK TRAINING NAV AND GUIDANCE ATTITUDE CONTROL PRACTICE RENDEZVOUS, SPACE LAB EXP
15,16	C-1	PROD VEHICLE	M	EARTH ORBIT-CIR	HABITATION-2 WEEKS SPACE LAB EXPERIMENTS RENDEZVOUS NAV AND GUID ATTITUDE CONTROL
17,18	C-1	PROD VEHICLE	M	EARTH ORBIT-ELLIP	NAV AND GUIDANCE, ATTITUDE CONTROL CREW TRAINING SPACE LAB EXP RADIATION TOLERANCE
19 20	C-2 (D)	PROD VEHICLE	UM	CIS-LUNAR 50,000 MI 150,000 MI	C-2 COMPAT RADIATION MEASURMENTS AND ANIMAL EFFECTS NAV AND GUIDANCE TRACKING SPACE LAB EXPERIMENTS COMM
21,22	C-2	PROD VEHICLE	M	CIS-LUNAR 150,000 MI	NAV AND GUIDANCE COMM AND TRACK, CREW TRAINING, RADIATION TOLERANCE ATTITUDE CONTROL
23,24,25	C-2	PROD VEHICLE	M	CIRCUM-LUNAR	CREW TRAINING SPACE LAB EXPERIMENT, HABITABILITY LUNAR RECON AND OBSERVATION COMM AND TRACKING NAV AND GUIDANCE PREP FOR LUNAR ORBIT
26,27,28,29	C-2	PROD VEHICLE	M	LUNAR-ORBIT	LUNAR OBSERVATION, LANDING SITE SELECTION, SPACE LAB EXPERIMENT LUNAR ORBIT, DE-ORBIT AND RETURN

Figure I-8-3. APOLLO/Saturn flight program

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vehicle flights. The abort loadings may be determined from the abort program (consisting of two on-the-pad aborts and two powered-flight aborts) and from flight 5, a pre-orbital abort condition, where thrust is supplied by the propulsion system, rather than by abort rockets. The abort program also furnishes impact data.

The escape subsystem will have a sample size of 5 flight tests plus additional ground tests, where possible. Since the structure of the escape subsystem has been included in the previous work no additional comment is required. The operation, after impact, of the recovery aids and life support system may be determined by drop tests and ground tests factored into the crew-training schedule. Reliability of the abort rockets and separation mechanism may be similarly determined from extended ground tests. Therefore, the escape subsystem basically is flight-tested also, once structural satisfaction has been shown as outlined above.

Injection into orbit, comparison of orbital tracking with in-space module position determination, vernier control of the Space Vehicle for rendezvous, deorbit, orbital changes and manually controlled maneuvers in orbit will all exercise the navigation and control, communications and instrumentation, and propulsion subsystems. As a prelude to midcourse guidance requirements these exercises will help to establish more definitely the requirements and reserves for the manned circumlunar flights. Midcourse guidance will be required for the cislunar tests, where a turn-around maneuver at apogee will also be required.

The attitude control function will be investigated on the circular orbit flight tests and on the elliptical orbit flights, also. The cislunar flights will provide midcourse data on this function. The requirements of attitude control, while in circumlunar or lunar orbit, will be well established.

The attitude control necessary for solar collection (for power) will be investigated in the cislunar flights. By extrapolation, the circumlunar and lunar orbit requirements will thus be available.

The cislunar flights will provide data on navigation accuracies and, therefore, a measure of the corrections required for cirumlunar and lunar orbit.

The life support subsystem will be required to provide full capability on all the longer length orbital and cislunar flights, checking out the shirt-sleeve environment of the module with crew on board. One purpose of the elliptical orbit flights is to furnish data on radiation tolerations and space radiation levels, prior to the commitment of the crew to cislunar flights. The environment of the cislunar flights should be close to the maximum possibility of solar flares and radiation levels to be expected in circumlunar or lunar orbits. The only remaining question to be answered is the possible existance of high radiation belts around the moon and this probably will not be determined until lunar flights have been accomplished. Prospector, and other lunar probe programs, may be a possible source for the needed data in this area.

Successful completion of this final phase of the R&D program will demonstrate the capability of the overall APOLLO Space Vehicle/Earth Support System to accomplish manned lunar orbital missions and safe return to earth. The overall system will then be considered qualified for operational use by the NASA in performing further scientific lunar missions, space explorations and eventual lunar landings.

APOLLO TEST MATRIX

PRELIMINARY DESIGN TESTS

TEST	SPECIAL ENVIRONMENTS	TEST ITEM	TEST FACILITY
I. VEHICLE DESIGN AND DEVELOPMENT			
A. Material Development			
1. Large Area Bonded Structure Tests (Strength, life and fabrication process integrity)		Simulated Large Sections of Command Module Structure	GE-MSVD Materials and Process Laboratory
2. Temperature Tests (Strength and life at extreme temperatures)	Various Thermal Conditions	Structure and Ablative Shield Samples	GE-MSVD Materials and Process Laboratory. GE-MSVD Structures Laboratory
3. Plastic, Honeycomb Structures - Outgassing Tests (Assessment of effect on strength and life)	Thermal - Vacuum	Structure and Ablative Shield Samples	GE-MSVD Materials and Process Laboratory. GE-MSVD Structures Laboratory
4. Ablation Tests (Effect of Angle of Attack)	Rocket Motor Exhaust Electric Arc	Models of Command Module	GE-FPLD Malta Test Station. GE-Switchgear Laboratory. GE-MSVD Space Sciences Laboratory
5. Inflatable Solar Collector Test (Effects of particle impacts; means of gas storage; compatibility with solar sensor)	Ambient, Vacuum, Thermal, Particle Impact.	Material Samples	GE-MSVD Structures Laboratory

Figure I-8-4. Preliminary design test matrix (Sheet 1 of 10)

APOLLO TEST MATRIX

PRELIMINARY DESIGN TESTS (Cont'd)

TEST	SPECIAL ENVIRONMENTS	TEST ITEM	TEST FACILITY
6. Optic Tests (Development of transparent materials for windows, astradomes, periscope ports, etc.)	Thermal Vacuum	Material Samples	GE-MSVD Materials and Process Laboratory. GE-MSVD Special Optics Facility
7. Wind and Shock Tunnel Tests - (Configuration Optimization)		Scale Models	GE-MSVD Space Sciences Laboratory. NASA-Langley Research Center
B. Protection Systems			
1. Thermal Protection Tests (Insulation methods for thermal protection of CM and MM interiors)		Small samples of Insulation Heat transfer model	GE-MSVD Structures Laboratory. GE-FPLD Malta Test Station
2. Solar Radiation Tests (Tests of radiators for cooling of vehicle.)		Parts or components of affected equipment	GE-MSVD Space Simulator
3. Meteoroid Bumper Tests (Resistance of structure and shield to meteoroid impact.)	Particle Impact	Samples of Structure and Ablative Shielding Material	GE-MSVD Structures Laboratory
4. Structure and Ablation Repair Tests - (Determine methods of repair of meteoroid impact damage.)	Ambient and Vacuum	Samples of Structure and Ablative Shielding Material	GE-MSVD Structures Laboratory. GE-MSVD Materials and Process Laboratory
5. Access Pressure Ports Tests	Pressure Vacuum	Sample Port Structures	GE-MSVD Structures Laboratory

Figure I-8-4. Preliminary design test matrix (Sheet 2 of 10)

APOLLO TEST MATRIX

PRELIMINARY DESIGN TESTS (Cont'd)

TEST	SPECIAL ENVIRONMENTS	TEST ITEM	TEST FACILITY
C. Separation Systems			
1. Light weight, large dia. shaped charge Tests		Boiler plate configuration of the Apollo Separation System.	Vendor facilities
2. Light weight, large dia. mechanical separation system tests (Feasibility of mechanical separation system for large diameter units)		Boiler plate configurations of the Apollo Separation System.	GE-MSVD Structures Laboratory
D. Recovery and Landing Systems			
1. Free Fall Drop Tests (Determination of flotation characteristics of command module.)		Floatable simulation of Command Module	GE-MSVD Structures Laboratory. Drop Test Tower.
2. Control Surfaces Tests (wind tunnel control surface tests)	Shock Tunnel Wind Tunnel	Models with Control Surfaces	GE-MSVD Space Sciences Laboratory. NASA-Langley Research Center
3. Wind Tunnel Wake Survey (Cover ejection characteristics)	Wind Tunnel	Boiler plate Command Module with ejectable parachute cover and parachute	NASA-Langley Research Center
4. Impact Attenuation	Free Fall	Boiler plate Command Module with impact attenuation devices	GE-MSVD Structures Laboratory. Drop Test Tower.

Figure I-8-4. Preliminary design test matrix (Sheet 3 of 10)

APOLLO TEST MATRIX

PRELIMINARY DESIGN TESTS (Cont'd)

TEST	SPECIAL ENVIRONMENTS	TEST ITEM	TEST FACILITY
5. Parachute Proof Tests (Dynamic tests of parachutes)	25000 ft. altitude to landing	Parachute system and boiler plate Command Module.	Aircraft drops
E. Advanced Fabrication Techniques			
1. Large Bonded Structure Tests (Integrity)		Large bonded structures such as Command Module	GE-MSVD Development Manufacturing. GE-MSVD Materials and Process Laboratory. GE-MSVD Structures Laboratory.
2. Beryllium Structure Development Tests (Structure fabrication process. Load and strength tests.)		Sections of structure	GE-MSVD Development Manufacturing. GE-MSVD Structures Laboratory.
3. Sandwich/Foam Structure Tests. (Construction process, load testing, fabrication of structures.)		Sample Testing	GE-MSVD Development Manufacturing. GE-MSVD Materials and Process Laboratory. GE-MSVD Structures Laboratory.
II. LIFE SUPPORT DEVELOPMENT			
A. Crew Functions Testing			
1. Display Development Tests (Scope, ease of reading, location, selection of information.)		Command and Mission Module mockups.	GE-MSVD Life Support Laboratory

Figure I-8-4. Preliminary design test matrix (Sheet 4 of 10)

APOLLO TEST MATRIX

PRELIMINARY DESIGN TESTS (Cont'd)

TEST	SPECIAL ENVIRONMENTS	TEST ITEM	TEST FACILITY
2. Work-Rest Cycle Tests. (Endurance Test of personnel, No. of manual functions required.)	7 psi Atmosphere	Mock-up in Chamber	GE-MSVD Environmental Laboratory. Johnsville Naval Research Lab.
3. Training requirements checkout (Sequence of training, material aids - mechanical and visual.)		Command and Mission Module Mock-ups	GE-MSVD Life Support Laboratory
4. Personnel Maintenance Capability Tests (Selection, location of repair, personnel capability to repair equipment.)		Command and Mission Module Mock-ups	GE-MSVD Life Support Laboratory
5. Zero "g" Capability Tests (Function, capabilities, under weightlessness.)	Weightlessness		WADD Facilities (Keplerian Trajectory Flights)
B. Biological Requirements Testing			
1. Acceleration Tests (Body limitations)	Acceleration		Johnsville Naval Research Laboratory
2. Vibration - Acoustic Noise (Human Tolerance and Means of Damping or Attenuating)	Vibration, Acoustic Noise (Recorded from Saturn Static Firing)	Command Module Mock-up	Johnsville Naval Research Laboratory
3. Food-Water-Waste Tests (Requirements to support life, max. and min. quantities, types, method to feed in weightlessness.)		Development Feeding System Waste Disposal Systems	GE-MSVD. Johnsville Naval Research Laboratory

Figure I-8-4. Preliminary design test matrix (Sheet 5 of 10)

APOLLO TEST MATRIX

PRELIMINARY DESIGN TESTS (Cont'd)

TEST	SPECIAL ENVIRONMENTS	TEST ITEM	TEST FACILITY
4. Space Suit Tests (Materials, habitability)		Development Space Suits	GE-MSVD Johnsville Naval Research Laboratory
5. Visual Motivation Tests (Visual motivation activity)		Forehead Ocular Camera	GE-MSVD Life Support Laboratory
III. TELEMETRY - RECORDERS			
1. Thermo Plastic Recorder Development Tests (Development, life, quantity tests.		Development Recorder	GE-MSVD Communications Laboratory
2. PCM/FM Encoder Development Tests (Data organization, type, life tests, etc.)		Development Encoder	GE-MSVD Communications Laboratory
3. 2 watt - 2 KMC Receiver-Transmitter (Development tests)		Development Receiver-Transmitter	GE-MSVD Communications Laboratory GE-MSVD Antenna Laboratory
IV INSTRUMENTATION			
A. Vehicle Instrumentation			
1. Sensor Tests (Abort mode sensors, propellent sensors in zero "g" field)		Development Models	GE-MSVD Instrumentation Laboratory
2. Control Instrumentation Tests (Tests on servo circuits)		Development Breadboards	GE-MSVD Instrumentation Laboratory
3. Communication Instrumentation Tests (Local communications, recorders)		Development Communications	GE-MSVD Communications Laboratory

Figure I-8-4. Preliminary design test matrix (Sheet 6 of 10)

PRELIMINARY DESIGN TESTS (Cont'd)

TEST	SPECIAL ENVIRONMENTS	TEST ITEM	TEST FACILITY
B. Mission Instrumentation			
1. Photographic Testing (Instant process techniques, store and transmit)		Development Models	GE-MSVD Instrumentation Laboratory
2. Customer Equipment Tests (Compatibility of customer furnished equipment)		Government Furnished Equipment	GE-MSVD System Engineering Laboratory
3. Television Equipment Tests (Resolution, lighting, location)		Development TV Models	GE-MSVD Communications Laboratory
C. Biological			
1. Cabin Environment Development Tests		Development Equipment	GE-MSVD Life Support Laboratory
2. Biological Instrumentation (Acceleration, Vibration, Acoustic Noise)		Personnel Development Equipment	GE-MSVD Life Support Laboratory
V. NAVIGATION, GUIDANCE AND CONTROL			
A. Propulsion System			
1. Attitude Control Propulsion (Development hot gas system tests, sizes, types)		Development Attitude Control Systems	GE-MSVD Navigation and Control Laboratory
2. Abort System Motor Tests (Materials, propellent)		Materials	Vendor Facilities
3. On Board Propulsion Tests (Materials improvement, fabrication, tolerance limits)		Materials	Vendor Facilities

Figure I-8-4. Preliminary design test matrix (Sheet 7 of 10)

PRELIMINARY DESIGN TESTS (Cont'd)

TEST	SPECIAL ENVIRONMENTS	TEST ITEM	TEST FACILITY
B. Astro Navigation Testing			
1. Astro Tracker Tests (Development, life, accuracy, repair and maintenance)		Development Model	GE-MSVD Navigation and Control Laboratory
2 Computer Tests (Life, accuracy, repair and maintenance)		Development Model	GE-MSVD Navigation and Control Laboratory
3. IR Sensor Tests (Development, life, accuracy, load optimum parameters)		Development Model	GE-MSVD Navigation and Control Laboratory
4. Sun Tracker Tests (Development, life, accuracy, load optimum parameters)		Development Model	GE-MSVD Navigation and Control Laboratory
5. Radar Altimeter Tests (Development, life, accuracy, load optimum parameters)		Development Model	GE-MSVD Navigation and Control Laboratory
C. Guidance and Control System Testing			
1. Control system tests (Hydraulic development, feedback problems)		Development Model	GE-MSVD Navigation and Control Laboratory
2. Radar Beacon Tests (Code, strength, life)		Development Model	GE-MSVD Navigation and Control Laboratory
D. Stabilization Systems			
1. Stable platform (Accuracy, reaction, life)		Development Model	GE-MSVD Navigation and Control Laboratory

Figure I-8-4. Preliminary design test matrix (Sheet 8 of 10)

APOLLO TEST MATRIX

PRELIMINARY DESIGN TESTS (Cont'd)

TEST	SPECIAL ENVIRONMENTS	TEST ITEM	TEST FACILITY
VI. ELECTRICAL POWER AND DISTRIBUTION			
A. Solar Collector Testing			
1. Inflatable Balloon Testing (Tests on inflatable type solar collectors for particle impact, etc.)	Particle Impact	Development Model Collector	GE-MSVD Structures Laboratory
2. Solar Cell (Optical and environmental parameters)	Solar Simulation	New Type Solar Cells	GE-MSVD Space Simulator
3. Collector Filters (Development, Life)		Development Models	GE-MSVD Electrical Power and Distribution Laboratory
B. Power Generator Testing			
1. Regenerative Fuel Cell (Cell Tests)		Single cells and development multi-cell module	GE-MSVD Electrical Power and Distribution Laboratory
C. Power Control Testing			
1. Lightweight-heavy power circuit testing		Development Power System Circuit Elements	GE-MSVD Electrical Power and Distribution Laboratory
2. Switching elements - (Special Environment)	Space Simulator	Development Switching Systems Elements	GE-MSVD Electrical Power and Distribution Laboratory. GE-MSVD Model Space Simulator

Figure I-8-4. Preliminary design test matrix (Sheet 9 of 10)

APOLLO TEST MATRIX

PRELIMINARY DESIGN TESTS (Cont'd)

TEST	SPECIAL ENVIRONMENTS	TEST ITEM	TEST FACILITY
D. Power Storage Testing			
1. Storage Battery Testing (load, life, operate at reduced pressure)	Command Module Pressure Environment	Development Storage Battery	GE-MSVD Electrical Power and Distribution Laboratory. GE-MSVD Environmental Laboratory
2. Emergency Storage Power (Methods and equipment to furnish emergency power and control)	Ambient. Command Module Pressure Environment	Development Emergency Storage Power System	GE-MSVD Electrical Power and Distribution Laboratory
VII. COMPONENT DEVELOPMENT			
A. Functional			
1. Pre-prototype Tests		Each Component	GE-MSVD Various Laboratories
2. Prototype Tests		Each Component	GE-MSVD Various Laboratories Vendor Facilities
B. Environments			
1. Environment Test	Special Environment for each particular component	Required Components	GE-MSVD Various Laboratories Vendor Facilities

Figure I-8-4. Preliminary design test matrix (Sheet 10 of 10)

APOLLO TEST MATRIX

PROTOTYPE DEVELOPMENT AND QUALIFICATION TESTS

TEST	SPECIAL ENVIRONMENT	TEST ITEM	TEST FACILITY
I. SUBSYSTEM DEVELOPMENT			
A Structure (R/V - Mission Module - Overall)			
1. Static Load Tests (Structure loading, auxiliary equipment load tests)	125% Design Limit loads	CM Structure MM Structure PM Structure Complete Vehicle Structure	GE MSVD Structure Laboratory
2. Structure Puncture and Crack Propagation (Vehicle integrity under loading, tears and impact)	125% Design Limit loads	CM Structure MM Structure	GE MSVD Structure Laboratory
3 Pressure Seal (Integrity of seals, water tightness)	Pressure Water sub-mersion	CM Structure MM Structure	GE MSVD Structure Laboratory
4. Thermal Tests (Special tests, thermal properties)	Thermal	Complete Structure	GE MSVD Structure Laboratory
B. Propulsion			
1. Abort			
a Case Hydro-Burst (max pressure)	Pressure	Abort Rocket Cases	Vendor Facilities
b Igniter Hydro-Burst (max. pressure)	Pressure	Rocket Igniter Units	Vendor Facilities
c. Igniter Hot Tests (functional under vacuum conditions)	Vacuum	Rocket Igniter Units	Vendor Facilities

Figure I-8-5. Prototype development and qualification tests (Sheet 1 of 12)

APOLLO TEST MATRIX

PROTOTYPE DEVELOPMENT AND QUALIFICATION TESTS (Cont'd)

TEST	SPECIAL ENVIRONMENT	TEST ITEM	TEST FACILITY
2. On Board			
a. Hydraulic Characteristics (Pressure drop, Spray pattern, Response)		Development Rocket Cases	Vendor Facilities
b Thrust Chamber Assembly Tests (Chamber Mat'l Selection, Firing Vibration, Vacuum)	Vibration Vacuum	Development Rocket Assy.	Vendor Facilities
c Tankage-Pressurization Tests (H_2O, Propellant, Expulsion Hot Firing)		Development Rocket Assy.	Vendor Facilities
d Gimbal Actuation System Tests (Response and Life)		Development Rocket Assy.	Vendor Facilities
e Altitude Control System Tests (Mat'l Firing, Vibration, Vacuum)	Vibration Vacuum	Development Rocket Assy.	Vendor Facilities
f. Control Instrumentation Test (Compatibility of Control Instrumentation with Rocket Motor)		Propulsion System Control Equipment	Vendor Facilities
3. R F. Interference Tests (R. F. Activation of explosives)		Communication Equipment Solid Propellants	AMR Range Facilities
4 Booster/Space Vehicle Separation Tests Separation Characteristics of Units		Booster/ Space Vehicle Separation System	GE-FPLD Malta Test Station. Vendor Facilities

Figure I-8-5. Prototype development and qualification tests (Sheet 2 of 12)

APOLLO TEST MATRIX

PROTOTYPE DEVELOPMENT AND QUALIFICATION TESTS (Cont'd)

TEST	SPECIAL ENVIRONMENT	TEST ITEM	TEST FACILITY
5. Booster/Abort System Separation Tests Separation Characteristics of Units		Booster/ Abort System	Vendor Facilities. GE Malta Test Station
6. CM/MM Space Vehicle Separation Tests Separation Characteristics of Units		CM/MM Space Vehicle System	GE Malta Test Station. Vendor Facilities
7. High Altitude Tests (Effect of Altitude on Separation Systems)	Vacuum or Altitude		GE Malta Test Station. Vendor Facilities. Range Facilities
C. Recovery and Landing			
1. Prototype Functional Tests (Functional check, compatibility of components)		Recovery Subsystem	GE MSVD Recovery Laboratory
2. Environment Tests	Vacuum Humidity Thermal	Recovery Subsystem	GE MSVD Recovery Laboratory. QCT Environmental Laboratory
3. Antenna Tests		Recovery Aids	GE MSVD Antenna Laboratory
4. Parachute Cover Ejection Tests		Parachute Covers	GE MSVD Structure Laboratory
5. High Altitude Drops			
a. Drogue Chute (Development Evaluation)	Altitude 25,000	Drogue-Chute Boiler Plate Command Module	White Sands Missile Test Range

Figure I-8-5. Prototype development and qualification tests (Sheet 3 of 12)

APOLLO TEST MATRIX

PROTOTYPE DEVELOPMENT AND QUALIFICATION TESTS (Cont'd)

TEST	SPECIAL ENVIRONMENT	TEST ITEM	TEST FACILITY
b. Main Chute (Development Evaluation)	Altitude 25,000	Main Chute	White Sands Missile Test Range
c System Drops (Complete system for Land Recovery)	Altitude 25,000	Recovery System	White Sands Missile Test Range
d. System Drops (Complete system for Water Recovery)	Altitude 25,000	Recovery System	Eglin AFB Range
6. Impact Attenuation (G Loading on Recovery Equipment effect)		Impact subsystem plus Boiler plate	Eglin AFB Range
7. Field Range (Recovery aids, Location, communications)		Recovery System plus Boiler plate	Edwards AFB Range
8. Set Out Test (Location, Recovery aid Evaluation)	Sea Condition	CM Boiler Plate	PMR Calif. Range Facilities
9. Maneuverability (Drift, Landing area)		Recovery System plus Boiler plate	Edwards AFB Range Facilities
D. Guidance and Control			
1. Prototype Functional Tests (functional compatibility)		Guidance and Control subsystem	GE MSVD Navigation and Control Laboratory.
2. Special-Sensor/Accuracy			
a. I. R. Sensor (functional)		IR Sensors	GE MSVD Navigation and Control Laboratory.

Figure I-8-5. Prototype development and qualification tests (Sheet 4 of 12)

APOLLO TEST MATRIX

PROTOTYPE DEVELOPMENT AND QUALIFICATION TESTS (Cont'd)

TEST	SPECIAL ENVIRONMENT	TEST ITEM	TEST FACILITY
b. Astro-tracker/Computer (functional)		Astro-tracker Computer System	GE MSVD Navigation and Control Laboratory
c. Radar Beacon (functional)		Radar Beacon	GE MSVD Navigation and Control Laboratory
d. Radar Altimeter (functional)		Radar Altimeter	GE MSVD Navigation and Control Laboratory
3. Earth/Star/Sun Simulation (Functional Operation in Space Simulation)	3 degree simulation Space-Solar simulation	Astro-tracker Subsystem	GE MSVD 3-degree of freedom simulator
4. Navigation and Control-Man Loop Simulation (Man-equipment integration)		Guidance and Control Subsystem	GE MSVD 3-degree of freedom simulator
5. Mission Synthesis and Computer Demonstration Tests		Guidance and Control Subsystem	GE MSVD Navigation and Control Laboratory. QCT Environmental Laboratory.
E. Environmental Control and Crew Support			
1. Functional-Compatibility		Life Support Subsystem	GE MSVD Life Support Laboratory
2. Special			
a. Centrifuge Tests (equipment effect)	Acceleration	Life Support Subsystem	Johnsville Naval Research Laboratory

Figure I-8-5. Prototype development and qualifications tests (Sheet 5 of 12)

APOLLO TEST MATRIX

PROTOTYPE DEVELOPMENT AND QUALIFICATION TESTS (Cont'd)

TEST	SPECIAL ENVIRONMENT	TEST ITEM	TEST FACILITY
b. Drop Test (equipment effect)		Life Support Boiler Plate	GE MSVD Structure Laboratory
c. Vibration Tests (equipment effect)	Vibration	Life Support Boiler Plate	GE MSVD QCT Environmental Laboratory
d. Habitability Tests (Life, task compatibility of man with equipment)		Life Support Mock-up	GE MSVD Life Support Laboratory
e. Sled Tests (Impact attenuation of restraint equipment)		Life Support Mock-up	Edwards AFB California
f. Vacuum Chamber Tests (Altitude effect on Life Support equipment)	Space Simulation	Life Support Mock-up	GE MSVD Life Support Laboratory
g. Flight Equipment Simulation (Simulator checkout)		Life Support Mock-up	GE MSVD Life Support Laboratory
h. Flight Profile Simulation (Simulator - flight profile checkout)	Space Simulation	Life Support Mock-up	GE MSVD Space Simulator
i. C-130 Flight "0" G (Partial task analysis)	Zero "G"	Life Support Mock-up for A/C	WADD Facilities
F. Communication and Telemetry			
1. Voice/TV Link (Functional, Subsystem Compatibility)		Communication Subsystem	GE MSVD Communication Laboratory
2. 2 KMC Transmitter-Receiver (Functional, Range Compatibility)		Communication Subsystem	GE MSVD Communication Laboratory

Figure I-8-5. Prototype development and qualification tests (Sheet 6 of 12)

APOLLO TEST MATRIX

PROTOTYPE DEVELOPMENT AND QUALIFICATION TESTS (Cont'd)

TEST	SPECIAL ENVIRONMENT	TEST ITEM	TEST FACILITY
G. Instrumentation			
1. Vehicle Instrumentation			
a Pressure/Therm/Altitude (Sensor functional Checks)	Specified Environment	Instrumentation Subsystem	GE MSVD Communication Laboratory
b. Control/Flight Control (Response, Indication)	Specified Environment	Instrumentation Subsystem	GE MSVD Communication Laboratory
2. Mission Instrumentation			
a. Photographic, periscope (functional Compatibility)		Instrumentation Subsystem	GE MSVD Communication Laboratory
3. Space Laboratory Instrumentation (functional tests of Special Instrumentation)		Instrumentation Subsystem	GE MSVD Communication Laboratory
4. Bio Med Instrumentation (Abort/Temp/Respiration/ Pressure)		Bio Med Instrumentation Subsystem	GE MSVD Communication Laboratory. Life Support Laboratory.
H. Power Supply			
1. Solar Collector (functional)	Solar Simulation	Solar Collector Subsystem	GE MSVD Electrical Power and Distribution Laboratory
2. Solar Array			
a. Solar Array/Fuel Cell Regulation (functional)	Solar Simulation	Solar Collector Subsystem	GE MSVD Electrical Power and Distribution Laboratory

Figure I-8-5. Prototype development and qualification tests (Sheet 7 of 12)

APOLLO TEST MATRIX

PROTOTYPE DEVELOPMENT AND QUALIFICATION TESTS (Cont'd)

TEST	SPECIAL ENVIRONMENT	TEST ITEM	TEST FACILITY
3. Life Tests			
a. Single Cell (functional, life)	Solar Simulation	Solar Collector Subsystem	GE MSVD Electrical Power and Distribution Laboratory
b. Mult. Cell (functional, life)	Solar Simulation	Solar Collector Subsystem	GE MSVD Electrical Power and Distribution Laboratory
4. Sun Seeker (functional)	Solar Simulation	Sun Seeker Subsystem	GE MSVD Electrical Power and Distribution Laboratory
I. Ground Support Equipment			
1. Prototype functional and compatibility (checkout of equipment)		1 complete set of ground support equipment including Range Equipment	GE MSVD Engineering Laboratory
II. SYSTEM DEVELOPMENT AND QUALIFICATION			
A. Command Module #1			
1. GSE Checkout (CM Ground Support Equipment)		GSE Equipment CM	GE MSVD Engineering System Laboratory
2. Subsystem Check		GSE Equipment Command Module #1	GE MSVD Engineering System Laboratory

Figure I-8-5. Prototype development and qualification tests (Sheet 8 of 12)

APOLLO TEST MATRIX

PROTOTYPE DEVELOPMENT AND QUALIFICATION TESTS (Cont'd)

TEST	SPECIAL ENVIRONMENT	TEST ITEM	TEST FACILITY
3. Functional and Compatibility Tests		GSE Equipment Command Module #1	GE MSVD Engineering System Laboratory
4. Acceleration	Acceleration	Command Module #1	Sandia Centrifuge
5. Vibration	Vibration	Command Module #1	GE MSVD Structures Laboratory
6. Shock	Shock	Command Module #1	GE MSVD Structures Laboratory
7. Temperature	Temperature	Command Module #1	GE MSVD Space Simulator
8 Vacuum	Vacuum	Command Module #1	GE MSVD Space Simulator
9. Radiation	Solar Simulation	Command Module #1	GE MSVD Space Simulator
10. System Demonstration		Command Module #1	GE MSVD System Laboratory
B. Command Module #2 + Mission Modules #1			
1. GSE Checkout (Mission Module) (Compatibility of equipment with mission module)		GSE Equipment (MM)	GE MSVD Engineering System Laboratory
2. Subsystem check (Tests on mission module subsystems received early)		GSE Equipment Command Module #2 + Mission Module #1	GE MSVD Engineering System Laboratory

Figure I-8-5. Prototype development and qualification tests (Sheet 9 of 12)

APOLLO TEST MATRIX

PROTOTYPE DEVELOPMENT AND QUALIFICATION TESTS (Cont'd)

TEST	SPECIAL ENVIRONMENT	TEST ITEM	TEST FACILITY
3. Functional and Compatibility (Mechanical and electrical subsystem compatibility, Functional checks on CM - Mission module system)		GSE Equipment Command Module #2 + Mission Module #1	GE MSVD Engineering System Laboratory
4. Pressure Seal Tests (pressure tests to insure seal integrity of CM - mission module system)		GSE Equipment Pressure Equipment Command Module #2 Mission Module #1	GE MSVD Engineering System Laboratory. QCT Environmental Laboratory.
5. Special Tests (checkout of weight and balance equipment. Special acceptance equipment checks, etc.)		Special Equipment such as weight and balance Command Module #2 Mission Module #1	GE MSVD Acceptance Test Laboratory
6. Customer furnished mission equipment compatibility (compatibility of GFE with mission module before installation of flight hardware)		Command Module #2 + Mission Module #1	GE MSVD Engineering System Laboratory
7. Crew Training (Use of Command Module - mission module for initial training on flight type hardware. Check of modifications to vehicle.		Command Module #2 + Mission Module #1	GE MSVD Engineering System Laboratory

Figure I-8-5. Prototype development and qualification tests (Sheet 10 of 12)

APOLLO TEST MATRIX

PROTOTYPE DEVELOPMENT AND QUALIFICATION TESTS (Cont'd)

TEST	SPECIAL ENVIRONMENT	TEST ITEM	TEST FACILITY
8. System Demonstration		Command Module #2 + Mission Module #1	GE MSVD Engineering System Laboratory
C. Command Module #3 + Mission Module #2 + Propulsion Module #3			
1. GSE checkout (Propulsion Module)		Complete GSE System (Apollo)	GE MSVD Engineering System Laboratory
2. Functional and Compatibility Tests		Complete GSE System Complete Apollo System (Command Module + Mission Module + Propulsion Module)	GE MSVD Engineering System Laboratory
3. Acceleration	Acceleration	Command Module + Mission Module	Sandia Centrifuge Facility
4. Vibration	Vibration	Complete Apollo Vehicle	GE MSVD QCT Environmental Laboratory.
5. Shock	Shock	Complete Apollo Vehicle	GE MSVD QCT Environmental Laboratory
6. Acoustic Noise	Acoustic Noise	Complete Apollo Vehicle	GE MSVD QCT Environmental Laboratory

Figure I-8-5. Prototype development and qualification tests (Sheet 11 of 12)

APOLLO TEST MATRIX

PROTOTYPE DEVELOPMENT AND QUALIFICATION TESTS (Cont'd)

TEST	SPECIAL ENVIRONMENT	TEST ITEM	TEST FACILITY
7. Temperature - Humidity	Temperature - Humidity	Complete Apollo Vehicle	GE MSVD QCT Environmental Laboratory
8. Solar Radiation	Space Simulation	Complete Apollo Vehicle	GE MSVD Space Simulator
9 Space Simulation	Space Simulation	Complete Apollo Vehicle	GE MSVD Space Simulator
10 System Demonstration		Complete Apollo Vehicle	GE MSVD System Laboratory

Figure I-8-5. Prototype development and qualification tests (Sheet 12 of 12)

APOLLO TEST MATRIX

PRODUCTION QUALIFICATION TESTS

TEST	SPECIAL ENVIRONMENT	TEST ITEM	TEST FACILITY
I. COMPONENT QUALIFICATION			
A. Functional Tests	Specified Environments	3 each Component	GE-MSVD QCT Environmental Laboratories
B. Acceleration Test	Specified Environments	3 each Component	GE-MSVD QCT Environmental Laboratories
C. Vibration, Shock, Acoustic Noise	Specified Environments	3 each Component	GE-MSVD QCT Environmental Laboratories
D. Altitude (Hard Vacuum)	Specified Environments	3 each Component	GE-MSVD QCT Environmental Laboratories
E. Temperature - Humidity	Specified Environments	3 each Component	GE-MSVD QCT Environmental Laboratories
F. Radiation (Solar)	Specified Environments	3 each Component	GE-MSVD QCT Environmental Laboratories
II. LIFE SUPPORT SUBSYSTEM			
A. Functional - Compatibility		Life Support Subsystem	GE-MSVD System Engineering Laboratory
B. Environmental			
1. Acceleration	Acceleration	Life Support Subsystem	GE-MSVD QCT Environmental Laboratory

Figure I-8-6. Production prototype qualification tests (Sheet 1 of 5)

APOLLO TEST MATRIX

PRODUCTION QUALIFICATION TESTS (Cont'd)

TEST	SPECIAL ENVIRONMENT	TEST ITEM	TEST FACILITY
2. Vibration - Shock - Acoustic Noise	Vibration, Shock Acoustic Noise	Life Support Subsystem	GE-MSVD QCT Environmental Laboratory
3. Thermal-Vacuum	Temperature Vacuum	Life Support Subsystem	GE-MSVD QCT Environmental Laboratory
III. NAVIGATION GUIDANCE - CONTROL SYSTEM			
A. Functional - Compatibility		Guidance and Control Subsystem	GE-MSVD System Engineering Laboratory
B. Environment			
1. Acceleration	Acceleration	Guidance and Control Subsystem	GE-MSVD QCT Environmental Laboratory
2. Vibration - Shock - Acoustic Noise	Vibration, Shock Acoustic Noise	Guidance and Control Subsystem	GE-MSVD QCT Environmental Laboratory
3. Thermal-Vacuum	Temperature Vacuum	Guidance and Control Subsystem	GE-MSVD QCT Environmental Laboratory
4. Space Simulation	Space Simulation	Guidance and Control Subsystem	GE-MSVD Three degree of freedom Simulator. Space Simulator
IV. COMMUNICATION SYSTEM			
A. Functional - Compatibility		Communications Subsystem	GE MSVD System Engineering Laboratory

Figure I-8-6. Production prototype qualification tests (Sheet 2 of 5)

APOLLO TEST MATRIX

PRODUCTION QUALIFICATION TESTS (Cont'd)

TEST	SPECIAL ENVIRONMENT	TEST ITEM	TEST FACILITY
B. Environments			
1. Acceleration	Acceleration	Communications Subsystem	GE-MSVD Environmental Laboratory
2. Vibration - Shock - Acoustic Noise	Vibration - Shock - Acoustic Noise	Communications Subsystem	GE-MSVD Environmental Laboratory
3. Vacuum	Vacuum	Communications Subsystem	GE-MSVD Environmental Laboratory
V. PROPULSION SYSTEM			
A. Abort			
1. Case Hydrotest		Abort System Rockets	Vendor Facilities
2. Motor Assembly Hydrotest		Abort System Rockets	Vendor Facilities
3. Temperature (Motor Hot Tests Environment)	Temperature	Abort System Rockets	Vendor Facilities
4. Vacuum (Motor Hot Tests Environment)	Vacuum	Abort System Rockets	Vendor Facilities
5. Vibration (Motor Hot Tests Environment)	Vibration	Abort System Rockets	Vendor Facilities
6. Humidity (Motor Hot Tests Environment)	Humidity	Abort System Rockets	Vendor Facilities
7. Sequential (Motor Hot Tests)		Abort System Rockets	Vendor Facilities
8. Jettison and Thruster Tests		Abort System Rockets	Vendor Facilities

Figure I-8-6. Production prototype qualification tests (Sheet 3 of 5)

APOLLO TEST MATRIX

PRODUCTION QUALIFICATION TESTS (Cont'd)

TEST	SPECIAL ENVIRONMENT	TEST ITEM	TEST FACILITY
B. On Board			
1. Humidity Tests	Humidity	Propulsion Subsystem	Vendor Facilities
2. Vibration Tests	Vibration	Propulsion Subsystem	Vendor Facilities
3. High-Low Temperature	Temperature	Propulsion Subsystem	Vendor Facilities
4. Life Tests		Propulsion Subsystem	Vendor Facilities
5. High-Low Voltage Tests (Functional)		Propulsion Subsystem	Vendor Facilities
6. Propellent-Tank and Pressurization System (Functional)		Propulsion Subsystem	Vendor Facilities
VI. C/M #4 + MM #3 + PM #2			
A. Functional and Compatibility		Complete Apollo System	GE-MSVD Engineering Laboratories
B. Environments			
1. Acceleration	Acceleration	Complete Apollo System (Modules)	Sandia Centrifuge Facility
2. Vibration	Vibration	Complete Apollo System (Modules)	GE-MSVD Environmental Laboratory
3. Shock, Acoustic Noise	Shock, Acoustic Noise	Complete Apollo System (Modules)	GE-MSVD Environmental Laboratory

Figure I-8-6. Production prototype qualification tests (Sheet 4 of 5)

APOLLO TEST MATRIX

PRODUCTION QUALIFICATION TESTS (Cont'd)

TEST	SPECIAL ENVIRONMENT	TEST ITEM	TEST FACILITY
4. Thermal - Humidity	Thermal Humidity	Complete Apollo System (Modules)	GE-MSVD Environmental Laboratory
5. Shipping and Handling	Shipping and Handling	Complete Apollo System (Modules)	GE-MSVD Engineering Laboratory Aberdeen Proving Grounds
6. Sand, Dust, etc.	Sand Dust	Complete Apollo System (Modules)	Holloman Air Force Base Facilities
7. Space Simulator Environment	Space Simulation	Complete Apollo System (Modules)	GE-MSVD Space Simulator
C. Post Evaluation			
(Functional test of system to determine the effect of environments on the system.)		Complete Apollo System	GE-MSVD Engineering Laboratory

Figure I-8-6. Production prototype qualification tests (Sheet 5 of 5)

9.0 Major Development Flight Program

9.1 RE-ENTRY AT ESCAPE VELOCITY

9.1.1 Introduction

In order to gain an understanding of the re-entry environment and the fundamental physical occurrences encountered by vehicles re-entering the earth's atmosphere at escape velocities it becomes desirable to fly probe type vehicles. Since the velocity of a vehicle travelling at 36,000 feet per second or beyond is at least the square root of two times larger than sub-orbital velocity, the kinetic energy of the gas particles is at least twice the value presently encountered by vehicles re-entering in the 20,000 fps range. Consequently, instead of equilibrium gas temperatures of approximately 7,000 degrees K and a level of ionization of approximately 1 percent, the equilibrium gas temperatures will now be of the order of 10,000 degrees K with levels of ionization of about 40 percent (this, of course, will depend on pressure). Therefore, there are tremendous uncertainties regarding the nature of the interaction between the vehicle and the environment. In particular, one can no longer predict the molecular transport phenomena in the gas with any degree of assurance (heat transfer, viscous forces, etc). Furthermore, one cannot assess the non-equilibrium state of the gas with any degree of assurance because of the sparsity of experimental data on chemical kinetics commensurate with this regime.

In order to design vehicles for these conditions, it is imperative that attempts be made to gather suitable experimental data during actual flight test conditions. This is because of the presence of the extremely large number of charged particles in this new type of flight environment and due to the lack of currently available adequate ground test facilities in which plasma phenomena can be simulated. Free flight experiments in which gross measurements can be taken of heat transfer, drag forces and gas composition (spectroscopic observations), will provide the necessary data which may be used to compare with newly developed theories

concerning these phenomena. From this, the evaluation and optimization of configurations, materials and other subsystems necessary to man-carrying space craft may then be made.

A flight test program is proposed then, to provide a solution to the difficult problem of initial data acquisition in the high velocity regime encountered by the returning space craft. The system would be designed utilizing as many existing items of hardware as possible. A chosen flight path would afford the possibility of "piggy backing" on an Atlas booster should one become available. The re-entry vehicle would be designed within the present state-of-the-art, to cut across a typical APOLLO type re-entry corridor with respect to velocity and altitude. It is considered that a lifting vehicle would be required to duplicate time or re-entry "G's", and that with the complexities to be encountered from velocity alone a vehicle well within the state-of-the-art, is imperative.

The General Electric Company's (Missile and Space Vehicle Department) experience in the design, manufacture and systems management of recoverable re-entry vehicles, and the variety of existing subsystems available to them, would be brought to bear in the design of this system. Analytical studies of the re-entry physics in the 36,000 fps range have already been initiated and considerable material testing is being conducted.

The proposed system would incorporate in its design such developed and proven components and subsystems as:

- NERV-type recovery package.
- RVX-2 interface and separation latches.
- NERV separation system.
- MK II - MK III C TP type attitude control system.

Further advantages are gained through:

- Utilization of Atlas guidance.
- Utilization of the Atlantic Missile Range Ascension splash net.
- ABL X-254 auxiliary booster.

The General Electric Company (Missile and Space Vehicle Department) also would employ its capability is such areas as field and range support, and data processing, reduction and analysis.

9.1.2 Summary

The desirability of obtaining inflight measurements of fundamental data peculiar to the re-entry velocity of the order of 36,000 fps has already been discussed in the Introduction. The flights proposed, in which sets of experimental data will be obtained, will offer the distinct advantage of "systems" testing under true environmental conditions. From these initial data certain major decisions can be made.

1. They will verify or disprove the present theoretical predictions of the basic problems encountered in this environment and define the magnitude of such problems.
2. They will indicate if it is necessary for major adjustments in fundamental thinking, numerical procedures, testing techniques, etc. In this event these tests will have:
   (a) identified problems that can be solved on a laboratory scale.
   (b) encouraged the more rapid development of specific facilities such as:
      (i) high performance shock tunnels.
      (ii) high performance uncontaminated arc facilities.

The proposed flight tests would contain within their payload instruments to make measurements of pressure, temperature, acceleration, and provide measurements

of pitch, yaw, and roll rates. In addition, erosion sensors would be provided to indicate the level of mass transfer experienced. Also, a spectrograph and MHD circuit would be included to determine the conductivity of the ionized sheath, and the spectral density of free electron energy.

Provision would be made to define the trajectory parameters (velocity and altitude as time variables) so that a base line may be established, thereby providing meaningful interpretation of other data.

The system proposed would observe the following ground rules:

1. Timeliness of the acquisition of these basic data dictates the design of a vehicle which may be operational in the immediate future. Therefore, the vehicle proposed should be within the state-of-the-art, thereby minimizing the period of design and development.
2. In all instances where existing hardware, qualified components or subsystems can be used without jeopardizing the objectives, they should be incorporated.
3. The system should be one within the overall capabilities of an Atlas D or E booster.
4. The flight path chosen should be such that if the opportunity of "piggy backing" is presented it may be utilized.
5. The RVX-2 interface should be maintained to eliminate establishment of new interfaces between the vehicle and the booster.
6. The system should in no way jeopardize the normal functioning of the Atlas booster.
7. The auxiliary booster should be one that is available with a minimum of lead time and is essentially fully developed.

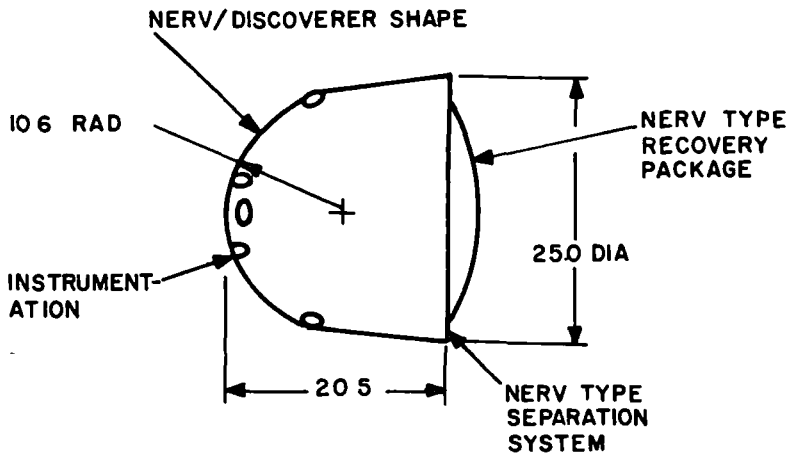
8. The configuration selected for the re-entry vehicle should comprise a basic shape; if possible one with which flight and ground test experience has already been obtained.

9. The system must provide re-entry conditions with respect to velocity and altitude commensurate with those expected to be experienced by vehicles returning to the earth's atmosphere at escape velocity.

The configuration selected for the proposed vehicle is a blunted sphere cone, $\theta = 10$ degrees 6 minutes, $Rn/Rb = 0.84$ (base diameter = 25 inches). This shape has already been extensively tested in ground facilities. Flight test knowledge is also available from the experience gained with such vehicles as "Discoverer" and "NERV." The re-entry vehicle would be designed conservatively so as to withstand the re-entry environment. The heat shield material chosen is commercial graphite which was selected not only because it is of the most resistant materials available, but because it can be utilized most effectively as a calorimeter due to its good conductive qualities and extremely small erosion. The re-entry vehicle is provided with a recovery system, similar to the flight-proven NERV package for maximum operational confidence and system weight economy.

The heat contained in the shield after re-entry would be sufficient to raise the temperature of the interior of the re-entry vehicle to a point where the instrumentation package would be "baked", thereby destroying recorded data. To preclude this, the heat shield is discarded at the time the recovery parachute is deployed, the shock load imposed by the parachute being sufficient to shear the foamed quartz and slip the heat shield from the vehicle's structure.

In order to properly place the re-entry vehicle in an escape velocity environment, an auxiliary booster and launching system incorporating orientation capability is required. Such a system is depicted in Figure I-9-1. The auxiliary booster which has been chosen is the ABL X-254.



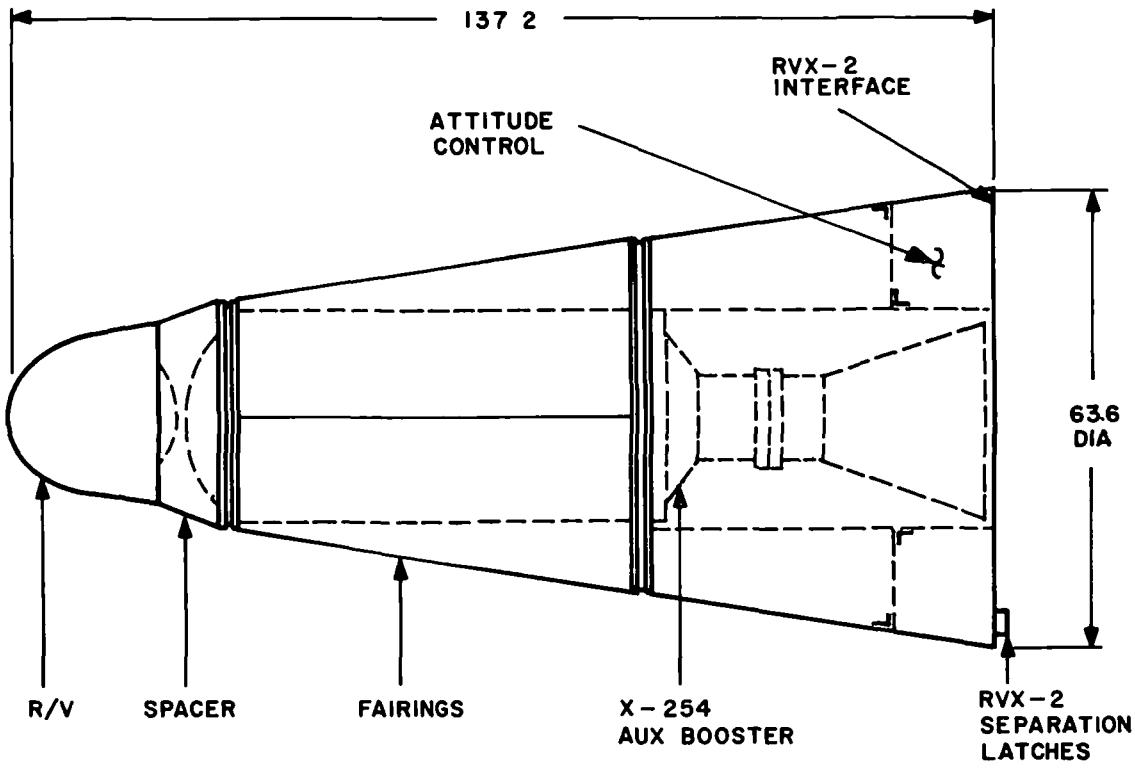


Figure I-9-1. Re-entry vehicle configuration

This will provide the vehicle with a ΔV of approximately 16,000 fps which when added vectorially to the velocity provided by the Atlas will constitute escape velocity. The attitude control system which gives the required orientation to the vehicle prior to the firing of the auxiliary booster is one which is similar to the type already flight tested in the MK II and MK IIIC TP vehicles. It is of the IR/magnetometer/pneumatic-jet type.

The sequence of operation of the proposed system is as follows· It is first boosted by the Atlas to separation altitude, whereupon the low-drag fairings are jettisoned and the system is separated from the Atlas. The attitude control system then orients the re-entry vehicle and booster to the correct re-entry angle with respect to local vertical and the system is spun up to hold this angle and minimize the effects of thrust misalignments. The booster is fired at approximately 1,000,000 ft and the re-entry vehicle separates from this booster just prior to re-entry. After re-entry the recovery parachute is deployed and recovery is accomplished.

9.1.3 Mission Profile

After the Atlas booster has completed its powered flight phase and just prior to separation of the proposed system, the midsection shrouds will be jettisoned. This point in the overall trajectory has been chosen so as to provide the least disturbance of the vehicle system, prior to orientation and spin stabilization. Separation of the vehicle system from the Atlas airframe is effected by the Atlas guidance system and is completely independent of the vehicle system. A signal indicating this separation is transmitted to the vehicle system principal programmer via the inflight disconnect jumper, this signal activates the vehicle timer. Allowing a minimum delay of 20 seconds to assure physical separation, the sequence of operations programmed for the vehicle system is then initiated, a pictorial presentation of this sequence is shown in Figure I-9-2.

SECONDS

1. 315 SEPARATION FROM ATLAS AIRFRAME; JETTISONING OF THE MID-SECTION SHROUDS.
2. 335 REORIENTATION COMMENCES
3. 1698 SPIN COMMENCES
4. 1718 AUXILIARY BOOSTER IGNITED
5. 1754 AUXILIARY BOOSTER BURNOUT
6. 1755 R/V SEPARATION
7. 1773 REENTRY COMMENCES
8. 1853 RECOVER INITIATED, PARACHUTE DEPLOYED, HEAT SHIELD DISCARDED; PLAYBACK–RECORD TRANSMISSION COMMENCED.
9. 2435 IMPACT

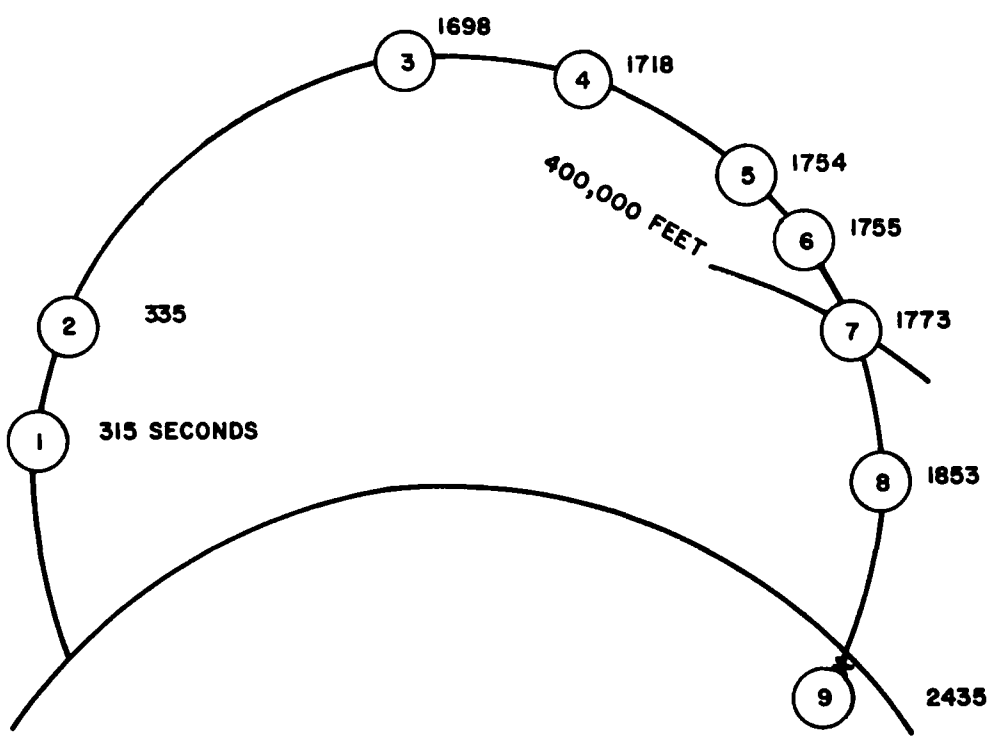


Figure I-9-2. Escape velocity mission profile

Following separation, the attitude control subsystem senses the orientation of the vehicle reference frame with respect to the earth's horizon and magnetic field. By comparing the intelligence received with the attitude desired (as preset in the control computer), the control then regulates the reorientation of the vehicle reference frame to conform with the attitude necessary to achieve satisfactory alignment of the auxiliary boosters thrust vector. In this way the correct attitude is acquired for the desired re-entry path angle and velocity. The necessary corrections in the vehicle attitude are accomplished by the utilization of thrust generated by the control subsystem gas jets.

The principal programmer, principal in the sense of distinguishing it from the programmer contained in the recovery subsystem, next initiates the firing of spin rockets which serve to maintain the attitude already acquired until the time of firing the auxiliary booster. The signal to ignite the auxiliary booster is then transmitted to the firing squibs. Electrical power to perform these operations is supplied by two 3/4 ampere-hour 28-volt d-c batteries that are housed in the aft support section. In addition, these batteries supply initial power to the instrumentation package within the re-entry vehicle; thereby avoiding a drain on the instrumentation package battery during the boost phase of flight.

As the booster is fired, the aft support section separates and electrical power is supplied to the instrumentation subsystem by its own battery. During this auxiliary boost phase the vehicle system is comprised of the re-entry vehicle, spacer and X-254 rocket, the other components of the original system having completed their purpose in the overall mission. The auxiliary booster is operated to its burnout, which is estimated to occur 36 seconds after ignition.

When the cessation of thrust is sensed by means of an acceleration switch within the instrumentation package, the explosive latches connecting the re-entry vehicle to the spacer and rocket motor case are fired, thus causing separation of the

re-entry vehicle. The "C" band transponder housed within the spacer continues its signalling, being independently powered by its own battery throughout all phases of the flight, it is felt that the location of the spacer, being slightly behind the re-entry vehicle will suffice to represent the re-entry vehicle for the purpose of tracking the system following separation from the Atlas airframe and prior to re-entry.

Physical re-entry into the earth's atmosphere is taken to begin at 400,000 feet altitude. The re-entry path angle at this altitude will be 111 degrees (below the local vertical) and the velocity will be approximately 36,000 feet per second. As the re-entry vehicle descends, measurements will be made and recorded on the playback recorder tape, no attempt will be made at direct transmission, for with the expected levels of ionization sucessful transmission is unlikely. Indeed, the system is to be designed so as to transmit only after the deployment of the chute at 40,000 feet. The system will continue to record until the re-entry "g" level becomes greater than 70 "g" (125,000 feet) from this point until peak "g's" (115) occur at approximately 100,000 feet, during which period the recorder will not function reliably. This phenomena may be considered to constitute a second "blackout" period.

The recovery system will be activated after the re-entry vehicle has reached Mach 1 (50,000 feet), the chute will be deployed at approximately 40,000 feet, at the same time the telescoping antenna will be extended and playback of the previously recorded data will commence.

The shock caused by deployment of the parachute will cause the heat protection (graphite and foamed quartz) to slip from the re-entry vehicle shell, thereby precluding the possibility of heat contained in the shield conducting to the interior of the vehicle and destroying the instrumentation.

The re-entry vehicle suspended from the parachute will impact in the vicinity of Ascension Island with a predicted total dispersion of 25 miles down range, 21 miles up range and $\pm$ 11 miles cross range, from the center of the splash net. The recovery

of the re-entry vehicle will be enhanced by its relatively slow descent from 40,000 feet and aided by signals emitted from the recovery beacon and the die marker dispersed at impact

9.2 FLYING WIND TUNNEL

9.2.1 Summary

The Flying Wind Tunnel is a re-entry vehicle system capable of placing APOLLO space craft models in an environment representative of the APOLLO re-entry corridor. With such a system it will be possible to make measurements of lift, drag, pitching moments, temperature and pressure with respect to the APOLLO models during re-entry under conditions not currently attainable in present ground based facilities.

The re-entry vehicle system may be likened to a "tractor-trailer" combination, an approach conceived by NASA, Langley Research Center, Langley, Virginia. The basic "tractor" element of the system is a modified RVX-2 re-entry vehicle, which serves to house the telemetry and instrumentation package, cameras, stable platform and the RVX-2 recovery package. The "trailer" which is ejected after the representative corridor has been traversed (400,000 to 150,000 ft.) supports six space craft models, mounted on pylons radiating from the basic structure. The six models are utilized in two basic groups, three to obtain force measurements and three for temperature and pressure measurements. These two groups are further subdivided such that the models are constrained at three critical angles of attack namely 0, 15, and 50 degrees. A reaction jet control subsystem is contained within the "trailer" or model support section which serves to orient and maintain the Flying Wind Tunnel within $\pm$ 3 degrees angle of attack along the trajectory path. The trailer section is attached to the aft frustum of the basic RVX-2 vehicle by a shaped charge separation device.

A nose fairing has been added to the RVX-2 basic vehicle, and serves to reduce the shock layer depth over the re-entry vehicle, thereby minimizing the pylon lengths, commensurate with placing the models in "free stream"

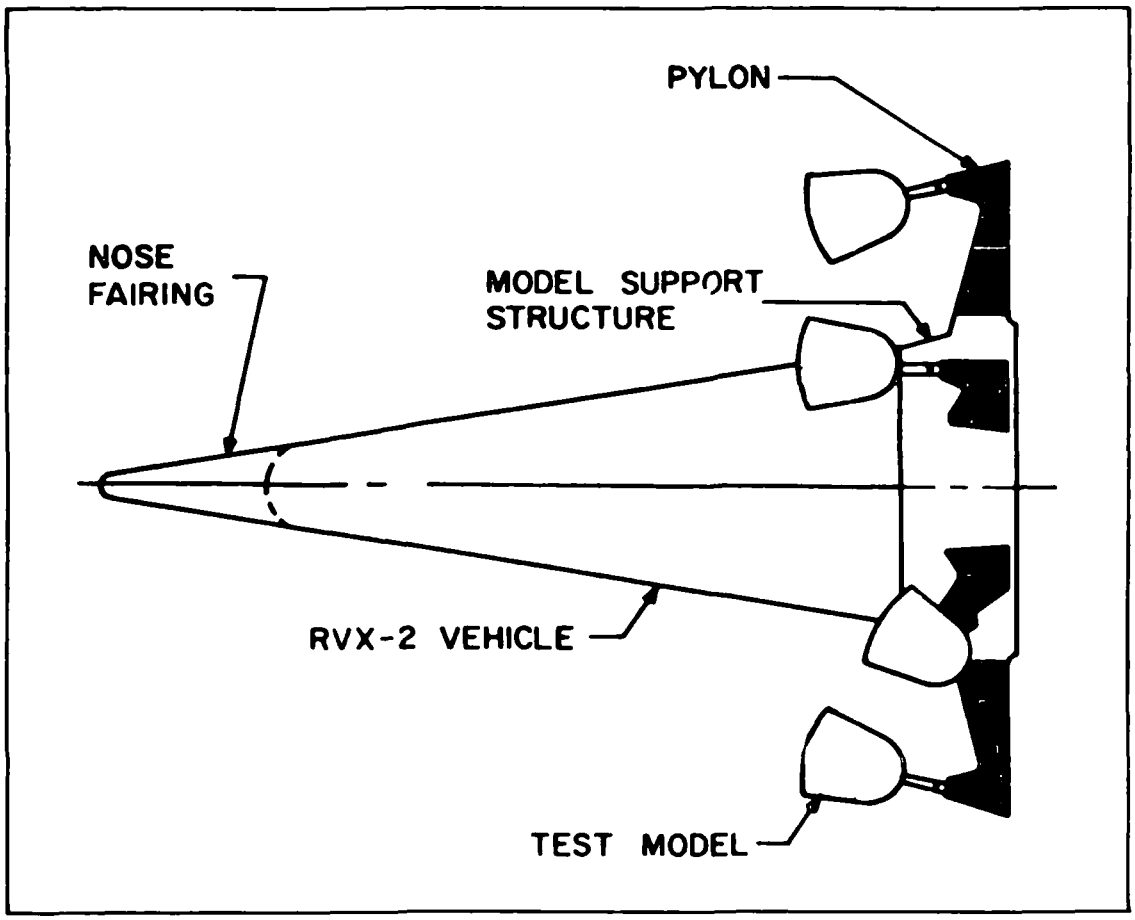


Figure I-9-3. System configuration

The Flying Wind Tunnel is boosted on a 4400 nmi minimum energy trajectory over the Atlantic Missile Range. Just prior to re-entry the vehicle is oriented along the velocity vector, utilizing the stable platform and reaction jet system. During initial re-entry, thermodynamic and aerodynamic measurements are made to determine the model behavior, and at approximately 150,000 feet the models and the nose fairing are ejected, thus reducing the system to the basic RVX-2.

At approximately 10,000 feet the recovery subsystem is activated and upon deployment of the parachute the vehicle velocity is reduced to 100 fps. After water impact the vehicle is retrieved, thereby permitting examination, reduction and analysis of the recorded data.

9.2.2 System Description

The fundamental objective of the Flying Wind Tunnel Program is to obtain aerodynamic and thermodynamic data on models at hypersonic speeds and altitudes from 400,000 to 100,000 feet. The approach proposed is to employ a large ballistic vehicle with an additional spacer section upon which are pylon mounted, models for measuring heat transfer, pressures, forces and moments. In addition to the basic vehicle and model section, a nose fairing will be required on the re-entry/recovery vehicle in order to minimize the interference of the parent vehicle flow field with the models. The entire system, including fairing and model section will be boosted on a nominal ballistic trajectory with an Atlas or Titan missile system. During re-entry the model section and nose fairing will be retained to an altitude of approximately 150,000 feet since the instrumented models will not be designed for severe re-entry, and the drag of the Re-entry Vehicle must be maintained at sufficient level to allow deployment of the recovery system. It may be seen from Figure I-9-4 that this approach will be capable of obtaining data at present beyond the range of existing ground facilities both in terms of environment and model size. In addition to the basic vehicle, model section, and separable fairing, the Flying Wind Tunnel will contain a recovery system and an

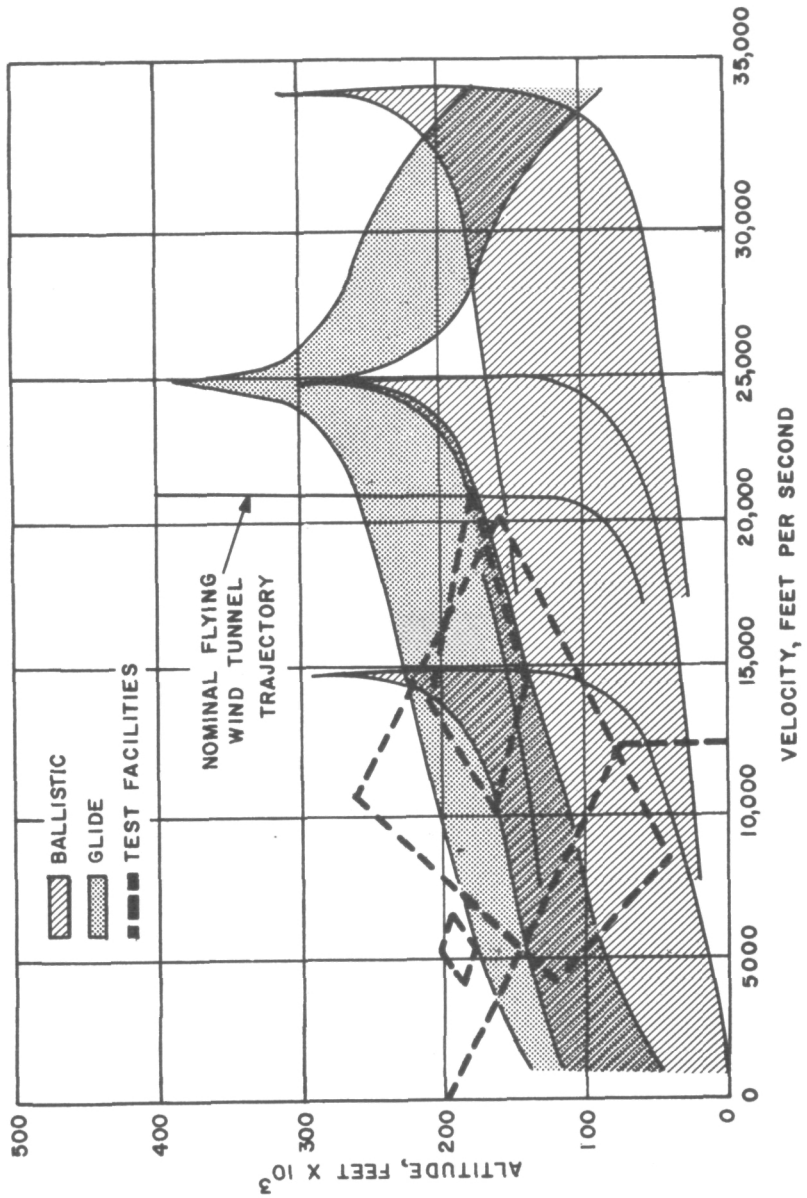


Figure I-9-4. Trajectories and aerodynamic simulation capability

attitude control system as well as a data acquisition system with a capability for obtaining complete model and vehicle motion data utilizing telemetry, oscillograph and tape recording, and optical measurements.

9.2.3 Mission Profile

The Flying Wind Tunnel 'Mission Profile' sequence of events is as follows:

A brief pictorial representation of this profile is indicated in Figure I-9-5.

1. Count-down and monitoring of payload vehicle through umbilical and in-flight disconnect.
2. Umbilical castoff and missile lift-off with final performance check through missile in-flight disconnect.
3. Peak dynamic pressure of powered flight at approximately Mach 1 at an altitude of approximately 30,000 feet.
4. Separation of the first stage booster above the sensible atmosphere.
5. Separation of the payload vehicle from the second stage at an altitude of approximately 1 million feet.
6. Re-orientation of the payload vehicle to predicted re-entry velocity vector at nominal range.
7. Initiation of camera coverage at an altitude of approximately 500,000 feet.
8. At an altitude of approximately 400,000 feet the initial effects of hypersonic re-entry are realized.
9. Loss of telemetry signal at an altitude of approximately 280 to 300,000 feet, with the initiation of the significant portion of the data acquisition phase and initiation of oscillograph recording.

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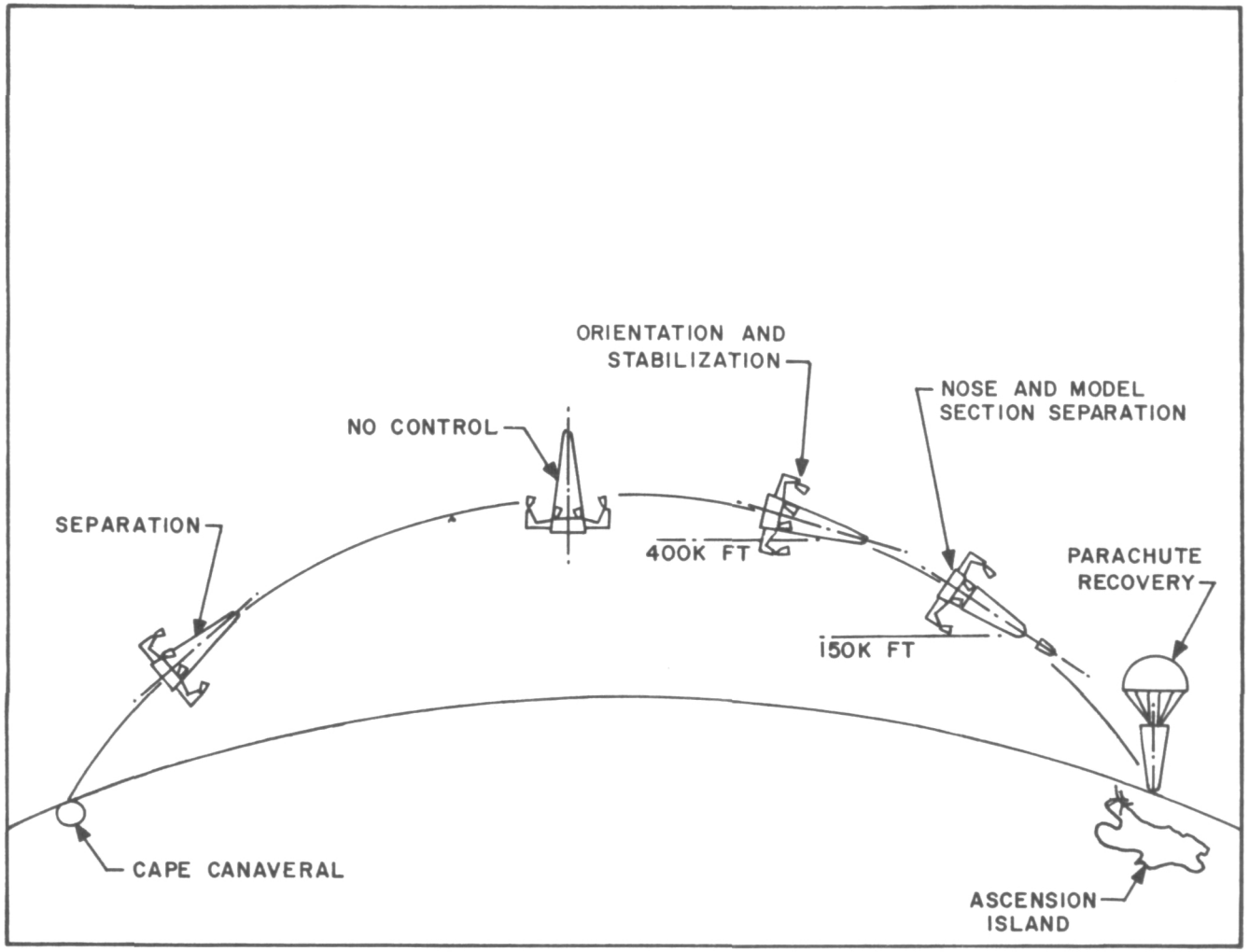

Figure I-9-5. Mission profile

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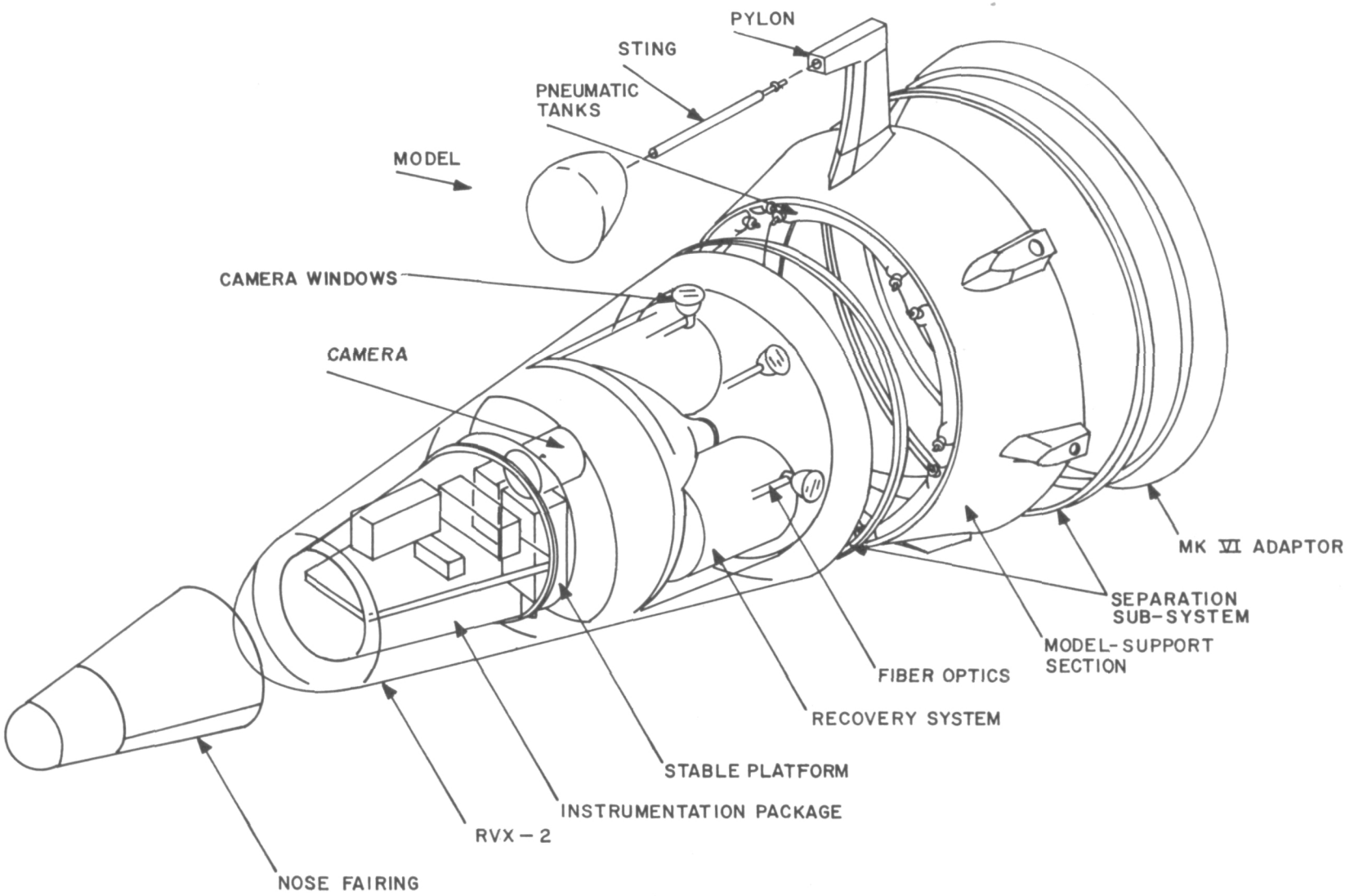

Figure I-9-6. Exploded view of flying wind tunnel system

10. At an altitude of approximately 150,000 feet the model section will be ejected and allowed to fall away behind the re-entry vehicle with the nose ejection following at a pre-determined time interval but not below 120,000 feet.

11. At a mach number approximately 10 recorder cutoff and initiation of telemetry playback.

12. At an altitude of approximately 10,000 feet the re-entry sequence is initiated by ejection of the re-entry vehicle aft cover with the subsequent timed ejection of the parachute system.

13. Impact in vicinity of Ascension Island and subsequent activation of recovery search aids including dye, SOFAR bomb and beacon.

9.3 RADIATION PROGRAM

9.3.1 Directionality Experiment

A program of experimentation is proposed to resolve one of the principal areas of uncertainty in the assumptions underlying the APOLLO Radiation Study. This is the question of the directionality of the proton radiation in the inner Van Allen Belt and of the proton flux in a solar flare. At the present time it is conservatively assumed that this radiation is omni-directional at every point. This results in high estimates of biological dose and excessive weight penalties when considering space vehicle shielding. Additionally, directionality is the key to the solution of the problem of active radiation shielding of space vehicles, which is the subject of current NASA sponsored study.

Two types of experiment will be required employing virtually the same instrumentation. For the inner Van Allen Belt, a vehicle of the type employed in the NERV project will carry aloft radiation detectors with a small view angle. The vehicle will be rotated with attitude information being recorded and correlated with radiation data. For solar flares a balloon-borne experiment would provide

the same information. Launch would be initiated by detection of the solar flare by riometer measurements.

9.3.2 Lunar Magnetic Field

Other data required for the APOLLO program regarding a possible radiation environment near the moon will probably be forthcoming from programs such as Ranger and Prospector. The principal information required is data on the magnetic fields in the vicinity of the Moon, confirming the assumption that there is no trapped radiation near that body.

9.3.3 Solar Flare Data

The pre-operational phases of APOLLO, will take place during a period of low solar activity. However, since the solar flare problem is one of the principal factors affecting the reliability of the APOLLO system, increased effort should be made be establish the characteristics of the solar flare radiation by making observations of the relatively few events which will occur in the period 1961-1966. This would require continued and increased support of present programs of observation and mesurements.

9.3.4 Instrumentation

The development of radiation dose instrumentation constitutes a long lead time item which should be undertaken at the outset of the APOLLO program. This essential "safety-of-flight" instrument is required for all manned missions and does not exist in operational form at this time. Current proposals such as the "Rem Meter for Manned Space Flight" by General Electric outline feasible solutions to the dose measurement problem. The importance of this device cannot be overestimated, and its development should be one of the principal objectives of early work in the instrumentation program for APOLLO.

9.4 WEIGHTLESSNESS

9.4.1 General

Although Mercury is expected to orbit this year, the problem still requiring resolution, with reference to manned space exploration, concerns man's ability to successfully adjust to and perform within the weightless regime for extended periods of time. In addition, serious consideration must be afforded such attendant problems as "g" tolerance decay, metabolic changes, and adaptability to changing "g's". These problems must be considered irreconcilable until relatively long term orbiting flights are implemented. It would be less than reasonable to summarily dismiss the possibility of adverse effects on the crew due to zero "g" even if current physiological or psychological data reveals no suspicion of detrimental effects.

Accordingly, it is proposed that short term and extended term weightlessness flight programs be implemented to assess the effects on man and equipment.

9.4.2 Short Term Zero "G"

Test programs to evaluate performance of such equipment as Lox converters, water collectors, propellant sensors, guidance and control subsystems, gaseous sensors, etc., have been identified in Section 8.0 of this volume. These test plans call for use of water immersion tests and aircraft Keplerian trajectory flights to simulate zero "g".

Such plans would be extended to include installation of full size command module and mission module mock-ups of the APOLLO Space Vehicle in C-130 and/or K-135 aircraft for purposes of evaluating cabin mobility and crew performance requirements under weightless conditions.

Additional weightlessness phenomena can be evaluated by incorporating biological experiments on such Programs as NERV, RVX-2, Discoverer and Scout.

9.4.3 Extended Term Zero "G"

The APOLLO implementation plan presented in this volume reflects that earth orbiting missions, both unmanned for equipment checkout, as well as manned, would be performed at the earliest possible date. The achievement of this early capability to orbit a human crew for say two weeks would permit the lunar mission phase to proceed with greater knowledge and higher confidence. The objectives of such early flights arise with greater significance when it is recognized that a redesign to vehicle or equipment may be required as a result of such flights.

In summary, then, although short term zero "g" can be simulated on programmed trajectory aircraft flights in order to provide insight to operation and performance of man and equipment, the problem of long duration weightlessness cannot be completely analyzed and evaluated without planned and phased orbital flight programs.

10.0 Ground Support Equipment, Field/Checkout, Field Facilities, and Logistic Support

10.1 GENERAL

Ground support equipment for the APOLLO Vehicle will be required from initial (factory) shipment of the vehicle through delivery of the recovered vehicle to its final location, either at GE/MSVD or some other location designated by NASA. Listed below are the major areas where ground support equipment will be located, and the type of equipment employed in each area.

10.1.1 Factory Area

a. Handling equipment

b. Checkout equipment (quantitative and qualitative, electrical, electro-mechanical, pneumatic, and/or hydraulic)

c. Servicing equipment (liquid oxygen, liquid nitrogen, liquid propellant, cooling air, etc.)

d. Ground instrumentation equipment

e. Shipping equipment

10.1.2 Field Hangar Area

a. Handling equipment

b. Transporting equipment (to transport APOLLO Vehicle between field hangar and launch site)

c. Checkout equipment (same as in factory area)

d. Static balance equipment

e. Servicing equipment (same as in factory area)

f. Ground instrumentation equipment

10.1.3 Explosives Installation Area

a. Handling equipment

b. Checkout equipment

10.1.4 Field Launch Area

a. Handling and mating equipment

b. Confidence checkout equipment

c. Control and monitoring equipment

d. Servicing equipment

e. Ground instrumentation equipment

10.1.5 Search and Recovery Areas

a. Search equipment located on Land Vehicles, Aircraft, and/or Surface Vessels

b. Recovery equipment located on Land Vehicles, Aircraft, and/or Surface Vessels

10.1.6 Ground Tracking and Communication Areas

a. Special ground tracking equipment for the APOLLO vehicle.

b. Special ground communication equipment for the APOLLO vehicle.

10.2 OPERATIONAL SEQUENCE

The following discussion describes the normal operational sequence for handling and checkout of the APOLLO Vehicle. Included are the operations for the handling and checkout phases, from vehicle manufacture through vehicle and crew recovery, and delivery to their ultimate destination.

10.2.1 Factory Area

Upon completion of the APOLLO Vehicle subsystem and system acceptance tests at the factory, the vehicle will be prepared for shipment to the launch complex at Cape Canaveral, Florida. (See Figure I-10-1.) For shipping purposes, the booster adapter section (main propulsion module) will be disassembled from the APOLLO Vehicle. Because of the large diameter of the propulsion section, it will be constructed in sections for ease of shipment to the field. It is planned to use air or highway transport facilities. All rockets, explosive and pyrotechnic devices will be shipped separately.

10.2.2 Field Hangar Area

When the APOLLO Space Vehicle, in its basic shipping subassemblies, arrives at Cape Canaveral, the sections of the propulsion section will be assembled together. The propulsion section will be mated to the remainder of the APOLLO Space Vehicle and the complete vehicle will be mounted on a transport vehicle as shown in Figure I-10-2. This transport vehicle will be used for transporting the fully assembled space vehicle within the hangar area itself and between the hangar area and the launch pad. Complete vehicle and module handling fixtures will be provided for hangar and field operations.

The complete hangar checkout for the APOLLO Space Vehicle is described below:

10.2.2.1 VISUAL INSPECTION

A complete visual checkout of the APOLLO Vehicle will be made to insure that no damage occurred during shipment from the factory to the hangar area.

10.2.2.2 SUBSYSTEM CHECKOUT

Using a Vehicle Checkout Console, as shown in Figure I-10-3, a complete electrical checkout, utilizing a ground power supply, will be made on each APOLLO Vehicle subsystem. The checkout console will control, monitor, and perform all

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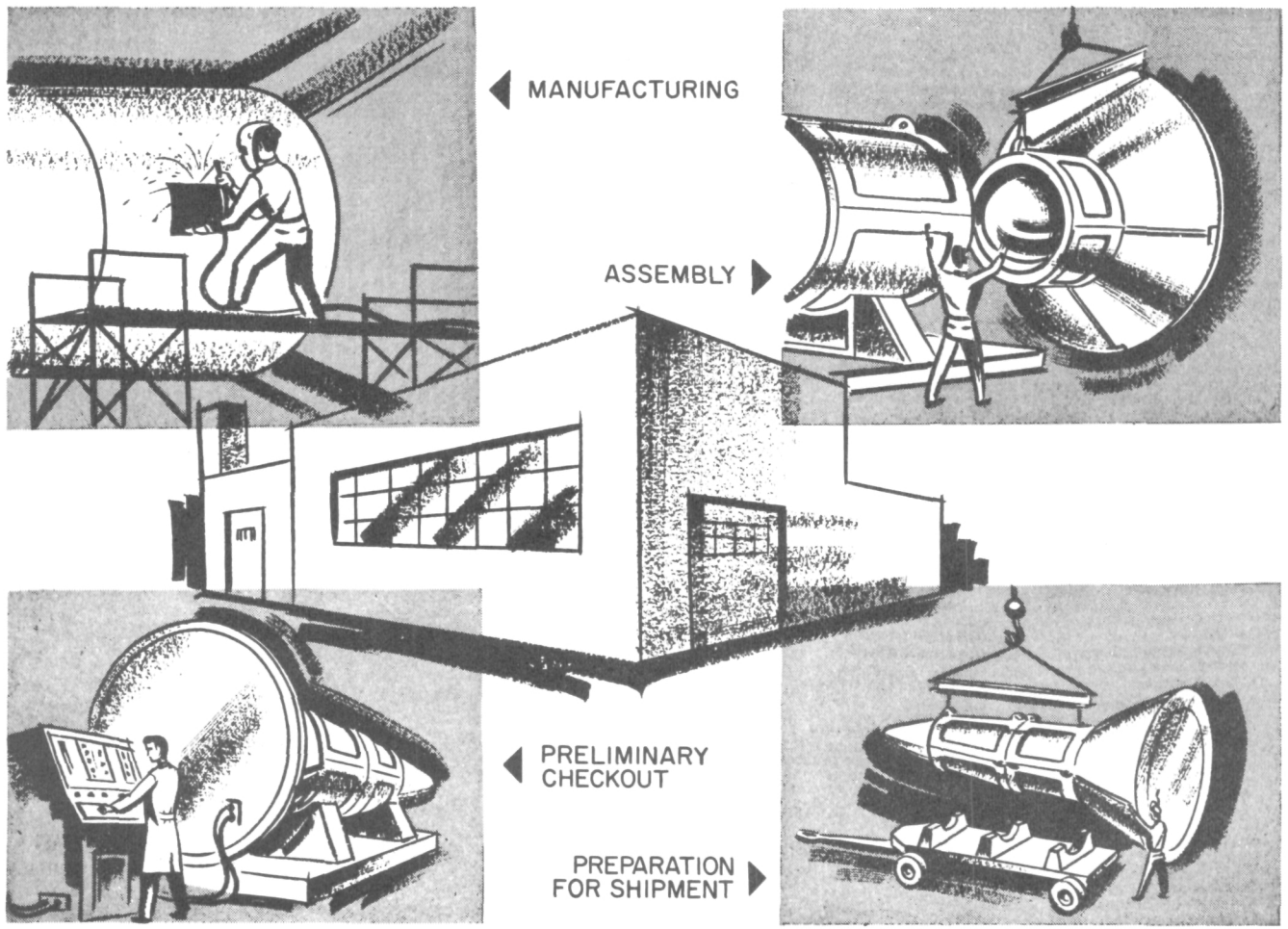

Figure I-10-1. Factory area operations

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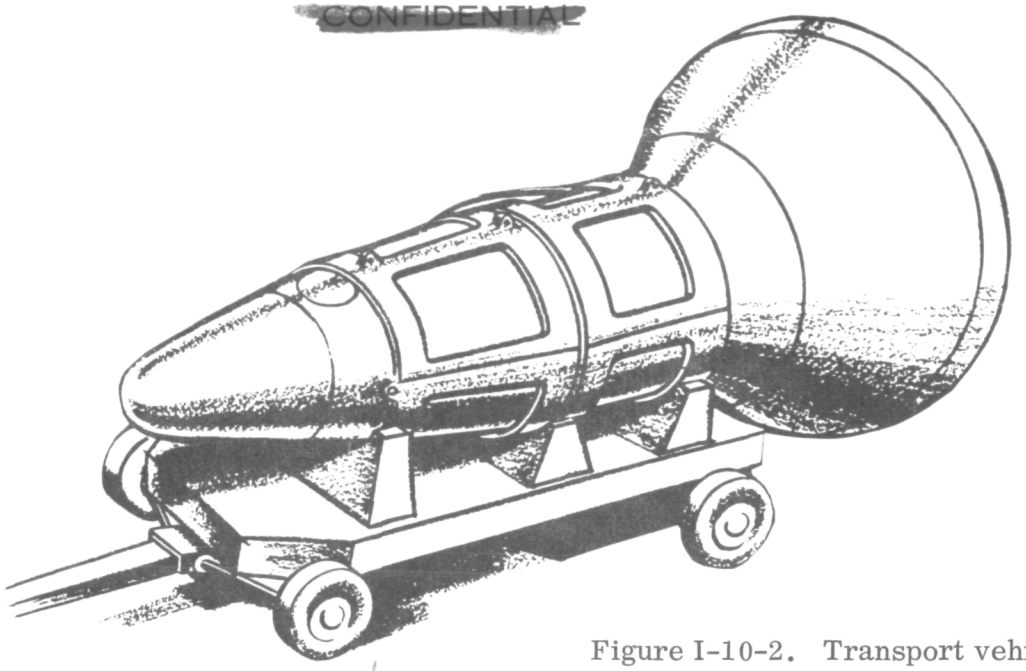

Figure I-10-2. Transport vehicle

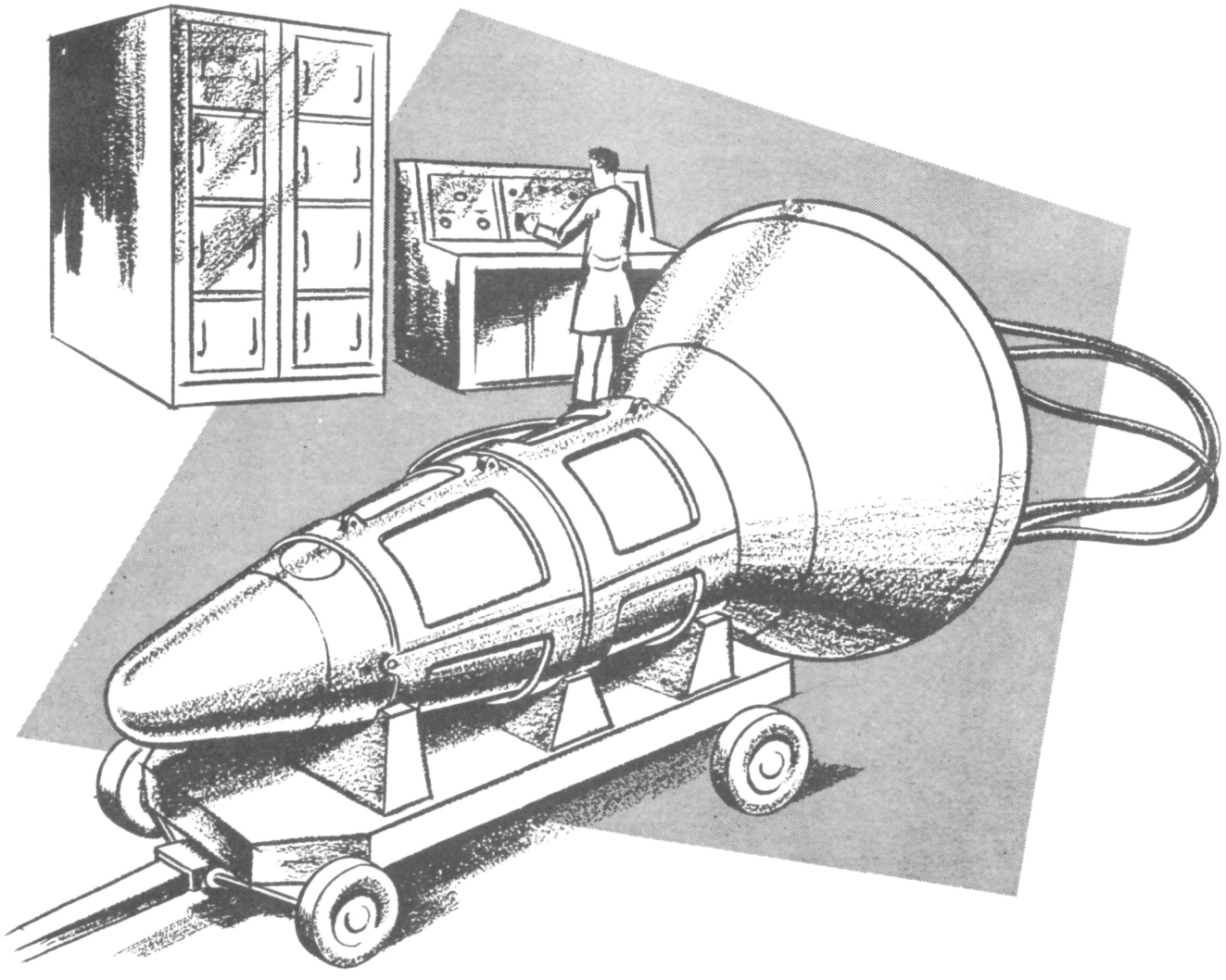

Figure I-10-3. Vehicle checkout console

of the detailed tests to isolate any faults in the subsystem down to the black box component level. Both an electrical ground disconnect and an inflight disconnect will be used for electrically connecting the checkout console to the APOLLO space vehicle.

A complete quantitative test of the electronic subsystem will be performed utilizing an Electronic Subsystem Test Set. This test of the instrumentation and communication subsystem will include such tests as:

a. Check of receipt and execution of commands

b. Verification of beacon response

c. Confirmation of proper operation of voice links, optical tracking aids, and telemetry channels

The electronic subsystem test set may be housed in an air-conditioned mobile van that can be used at the explosive installation area, and the launch pad as well as in the hangar area. This equipment will be capable of testing the electronic subsystem by hardwire, through the electrical ground disconnect, or by free radiation.

By means of a Vehicle Dynamic Test Simulator, as shown in Figure I-10-4, a complete dynamic test of the guidance and control subsystem will be made. Using an automatic programmer controlled through a Dynamic Test Monitoring Console, the guidance and control subsystem will be checked for correct response in each of the three axes of roll, pitch, and yaw. Correlation of the telemetry response will also be obtained at this time. Where possible, simulation of all one-shot type devices (squibs, rockets, etc.) will be provided.

A complete check will be made of the environmental subsystem using the Vehicle Checkout Console. This check will include verification and calibration of the associated instrumentation and crew displays. Such parameters as partial pressures of oxygen, nitrogen, carbon dioxide, and water vapor, as well as cabin temperature

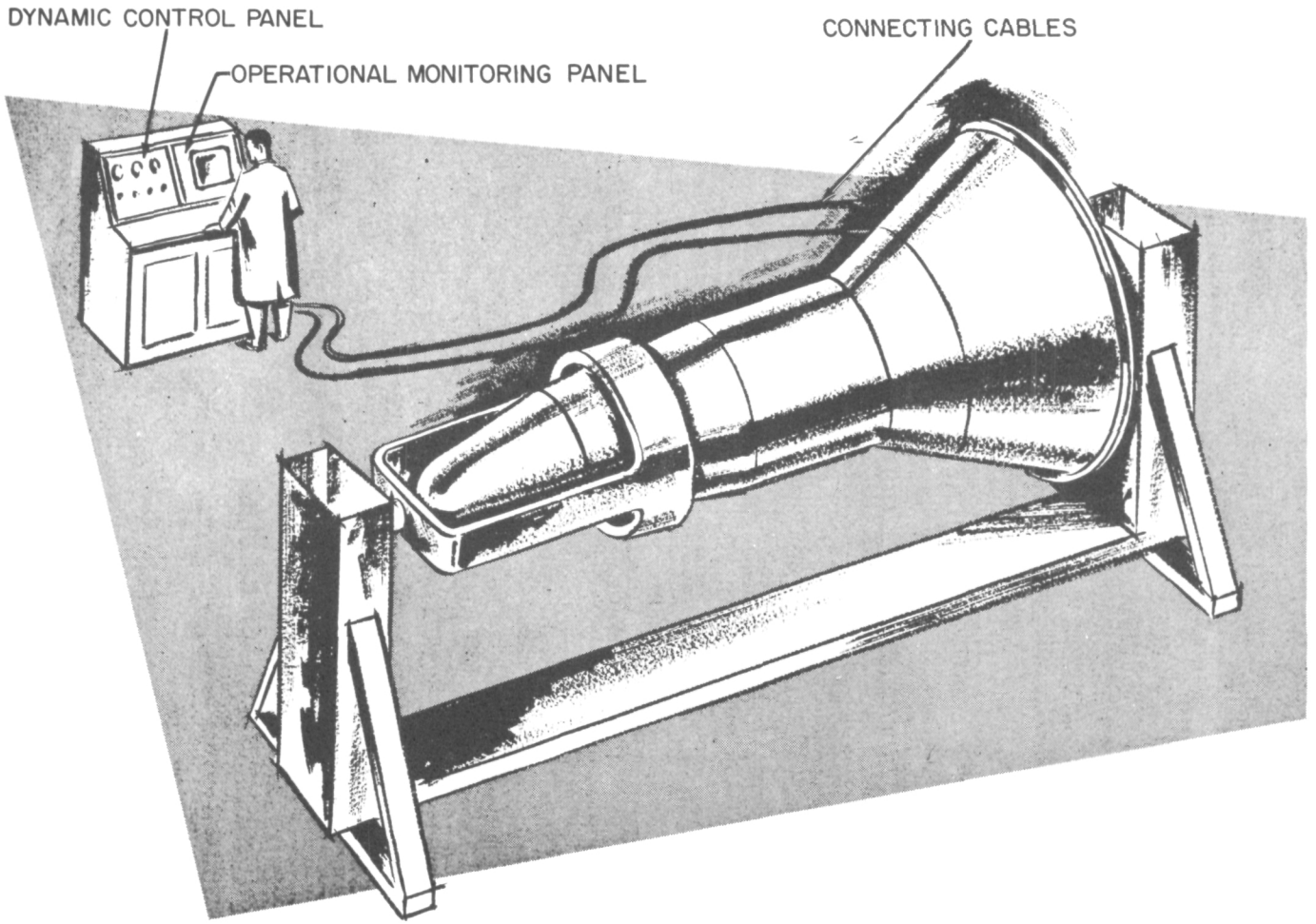

Figure I-10-4. Dynamic test simulator

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and pressure will be measured and compared with the readings from the displays for verification of calibration.

10.2.2.3 PLUMBING SYSTEM LEAK DETECTOR TESTS

After the vehicle system has been successfully checked, leak tests will be made of the vehicle plumbing systems, oxygen, nitrogen, pneumatic, and/or hydraulic. These tests will be similar, in nature, to the checks that have been made in the past on other space vehicle and re-entry vehicle systems developed by GE-MSVD. The tests will be run with the tanks pressurized to the "on stand" pressure. The pressure in each system will then be monitored for a sufficient length of time to verify that the system is tight.

In the event that leaks are detected, a small amount of helium will be used to isolate the leak. During these tests, certain valves will have to be energized on command from the Vehicle Checkout Console, and may, therefore, be disconnected from the airborne commands and tied back into the ground support equipment.

For this reason, this test must precede the full system checkout, since the latter will verify that these solenoids have been reconnected to the airborne system. If high pressures and large volumes of gases are involved in any of these systems, these tests will be performed in a special high pressure test area. The operating personnel will be protected against a catastrophic failure of the system.

10.2.2.4 CABIN AREA LEAK DETECTOR TESTS

A leak detector test is required to determine the air tight integrity of the cabin area and of the bulkhead door, between the mission module and the command module. A helium tracer gas leak detector, developed on a previous biomedical program by GE-MSVD, will be used for these tests. This equipment utilizes the mass spectrometer principle, and the basic design can be adapted for the APOLLO Vehicle. This particular system will not be affected by the heat generated due to the occupants or the operation of any electronic equipment. This will be a quantitative

type of test, insuring that the vehicle will not incur a total leakage in excess of the maximum allowable. If the cabin area has a total leakage which is more than tolerable, suspected sources of leakage will be subjected to a jet of helium to pinpoint the location of the leak.

10.2.2.5 WEIGHT AND BALANCE CHECKS

Analysis of re-entry vehicle dynamics in this and other re-entry vehicle programs has shown that a balance check in the field, in addition to the complete balancing procedure performed in the factory, is essential to assure impact of the re-entry vehicle within the specified impact area and to minimize the control forces required. A vehicle leaving the factory would be dynamically balanced, weighed, and the moments of inertia and the center of gravity measured.

While in the field, such operations as retrofitting, replacing of components, and variations of crew weight will affect the balance. As each change to the balance is performed, a notation describing the weight and location of the change will be recorded in a log book. Following the last modification, several calculations will be performed to determine the respective changes to the balance, weight, moments of inertia, and centers of gravity location.

For measuring the weight and center of gravity of the APOLLO Vehicle in the field, weight and static balancing equipment, as indicated in Figure I-10-5, will be developed which will be rugged and operationally simple. This equipment will be capable of checking the measurements of the command module (which will weight approximately 5, 000 pounds), as well as the entire space vehicle in its launch configuration (which will weigh approximately 15, 000 pounds). In each case, these weight and balance checks will be made with the actual crew and complete flight equipment in place.

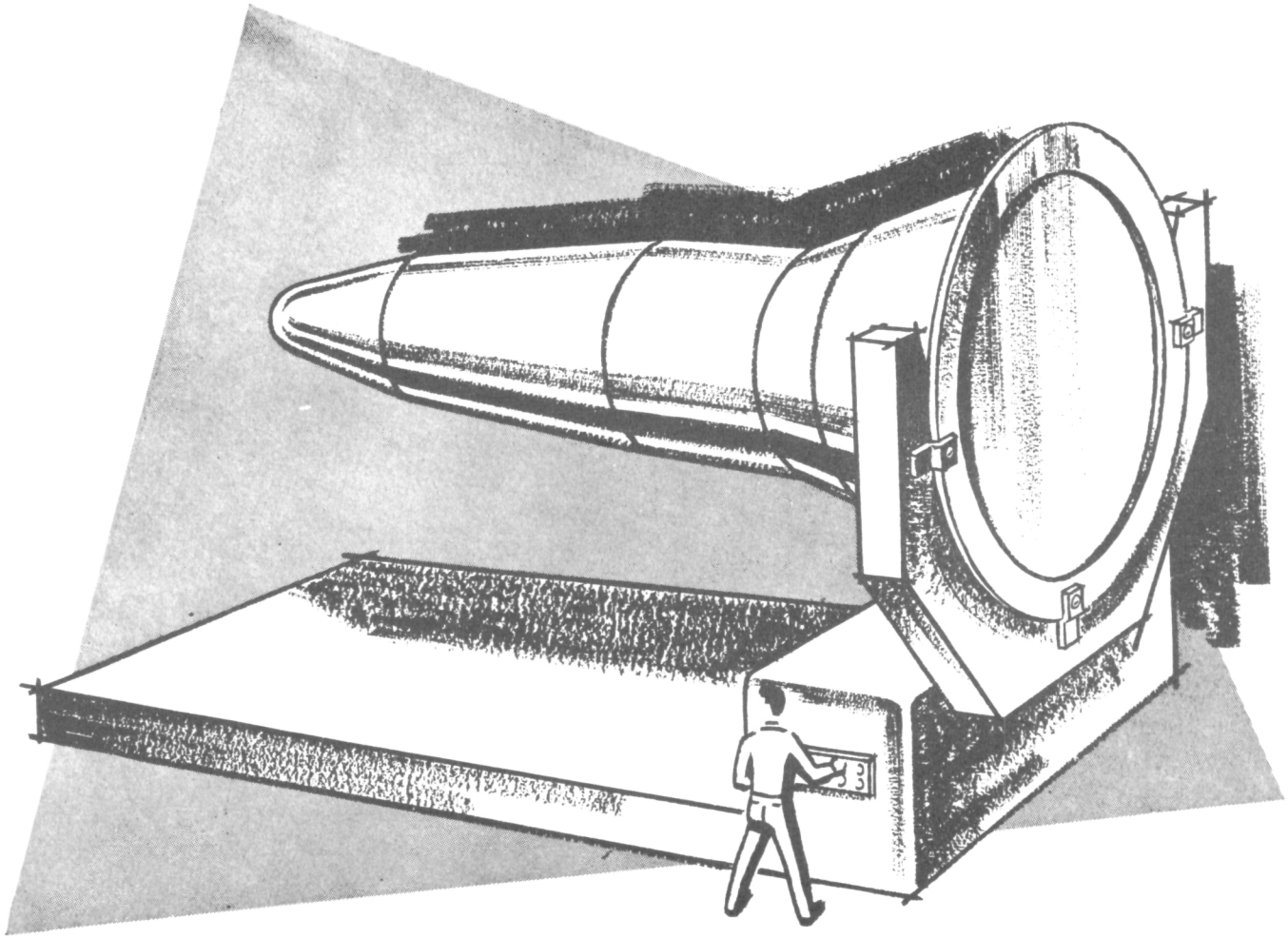

Figure I-10-5. Weight and static balance equipment

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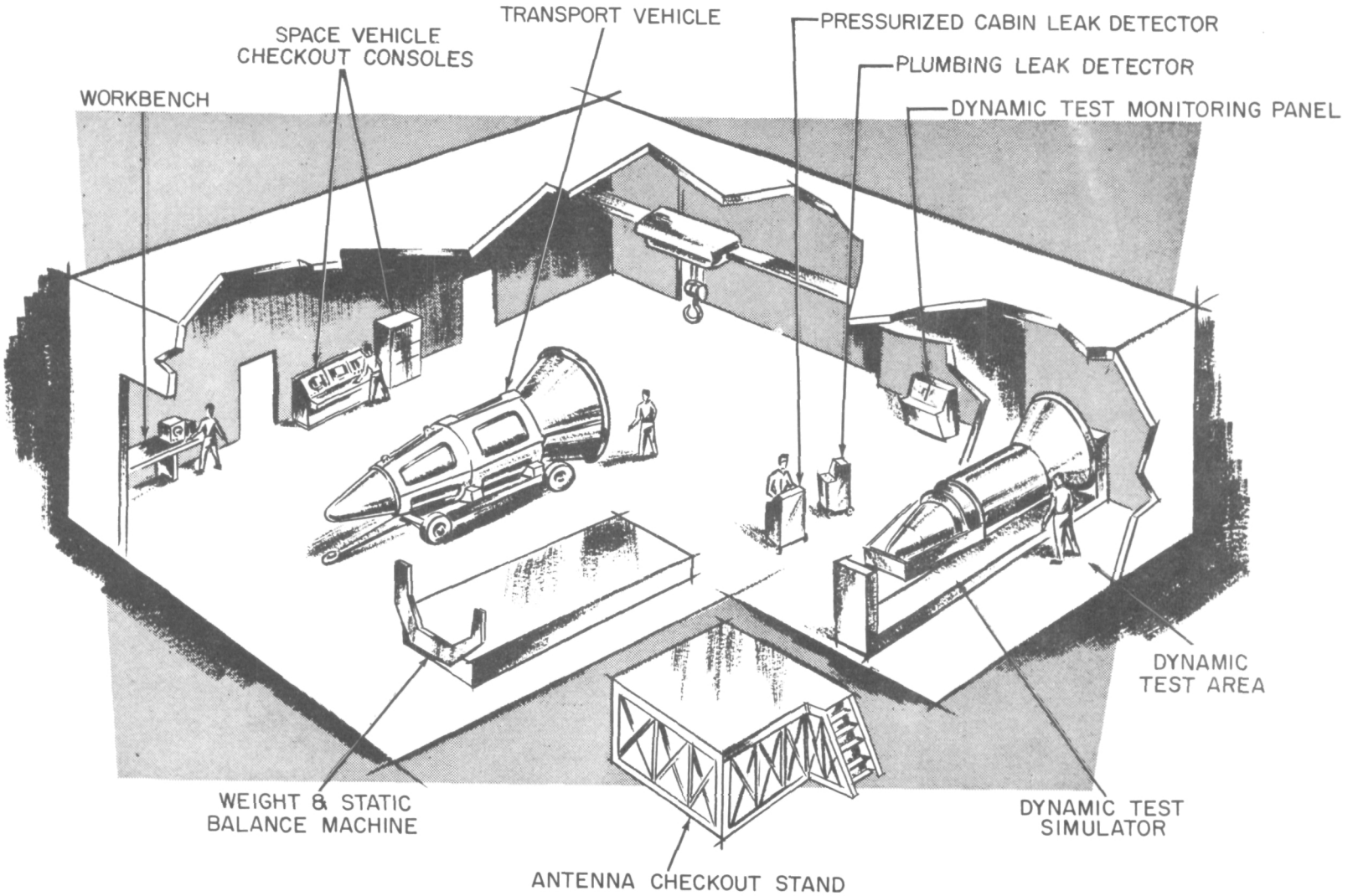

Figure I-10-6. Field hangar area

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10.2.2.6 SERVICING EQUIPMENT

The necessary servicing equipment for supplying liquid oxygen, liquid nitrogen, liquid propellant, gaseous nitrogen (high and low pressure), ground cooling, purging, etc. to support the hangar tests will be provided.

10.2.2.7 SYSTEM CHECKOUT

With the completion of the tests on the subsystems, leak tests, weight and balance checks, etc., an electrical check will be made of the entire APOLLO Vehicle system, again utilizing the Space Vehicle Checkout Console. This test will check continuity of the electrical system as well as inter-action and compatibility of the subsystems with each other. It may be that some of the tests, and checks made on a subsystem basis, will be repeated at this time to determine the effects of interaction. The APOLLO Vehicle is now ready to be transported to the launch pad for flight readiness tests.

10.2.3 Vehicle Assembly/Disassembly

When assembly/disassembly becomes necessary, it is performed in the field hangar. The general order of assembly/disassembly is illustrated in Figures I-10-7 to I-10-14.

10.2.4 Launch Pad-Flight Readiness Tests

From the hangar, the APOLLO Vehicle will be transported on the transport vehicle to the launch pad for the flight readiness tests. These tests are to prove mechanical and electrical compatibility of the APOLLO Vehicle with the Saturn Booster. All of the launch pad ground support equipment will be utilized prior to and during these tests.

Before the booster tests are started, an APOLLO Vehicle Simulator will be operated to check the launch pad cabling and electrical ground equipment. Mechanical compatibility will be confirmed upon mating the Space Vehicle to the booster. Electrical compatibility will be confirmed using the Space Vehicle Operating Console and the Electronic Subsystem Test Set. The entire vehicle will be serviced by the launch site cooling and purging equipment and other servicing equipment, as necessary.

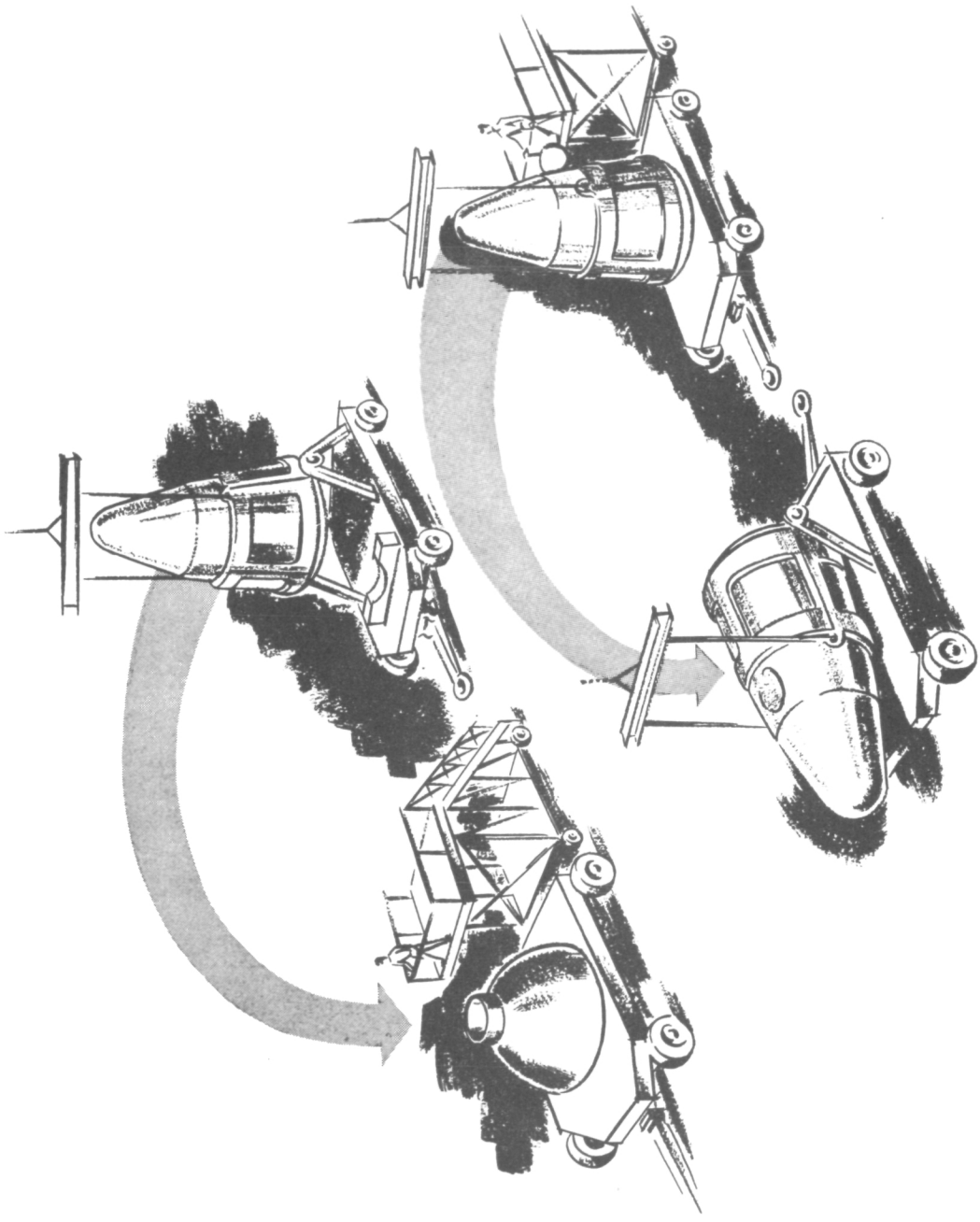
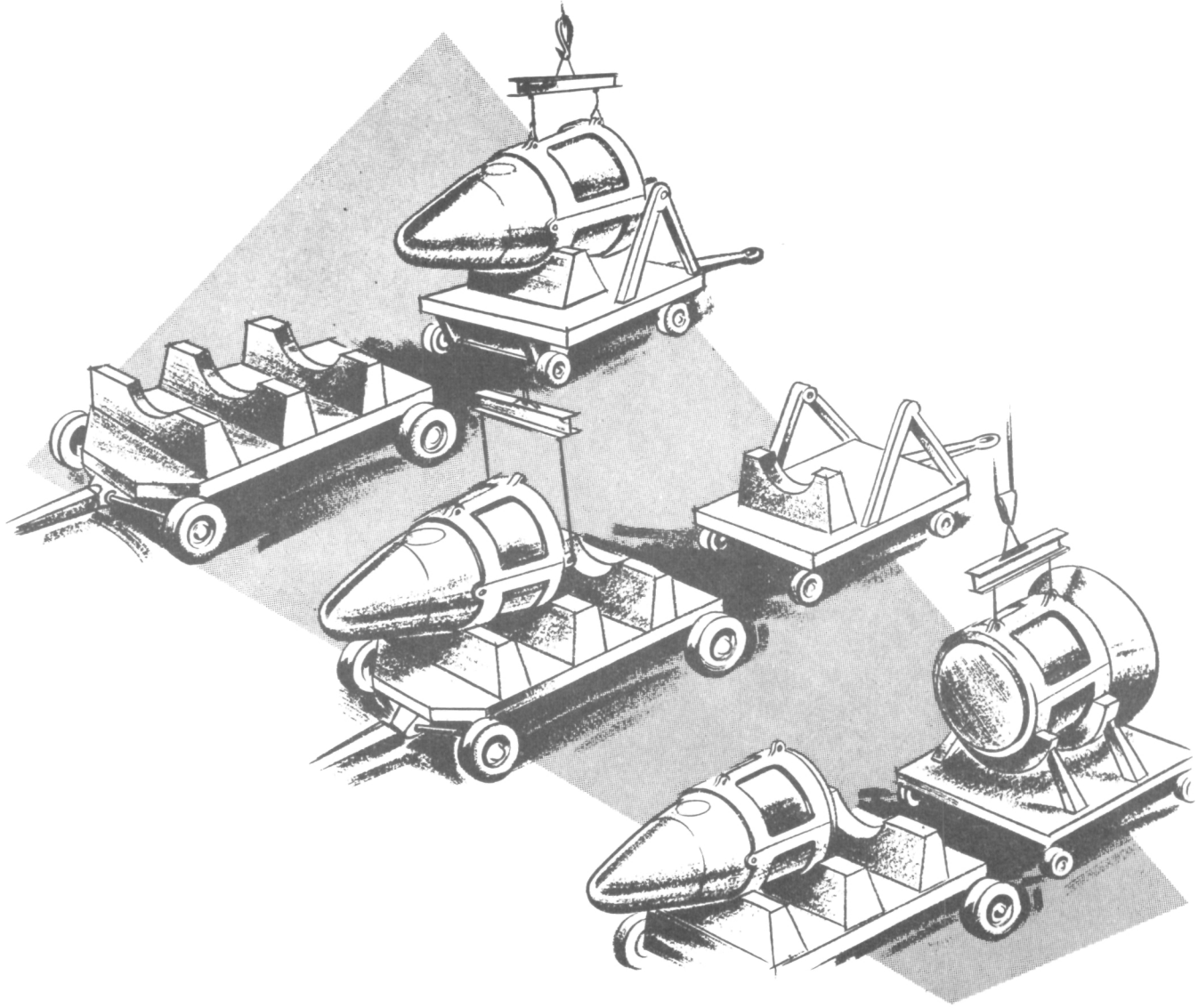


Figure I-10-7/I-10-8. Vehicle assembly/disassembly equipment



Figures I-10-9/I-10-10/I-10-11. Vehicle assembly/disassembly equipment

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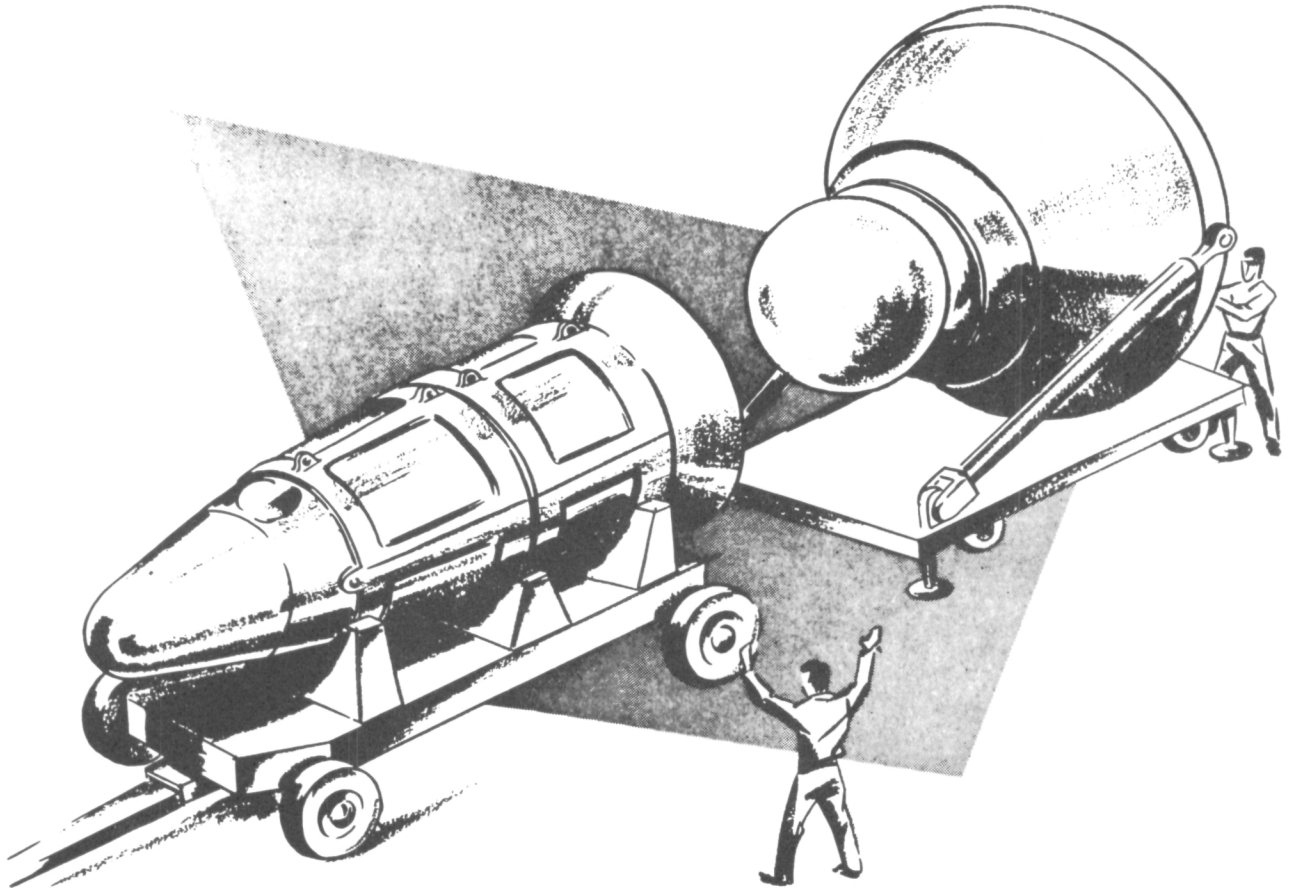

Figure I-10-12. Vehicle assembly/disassembly equipment

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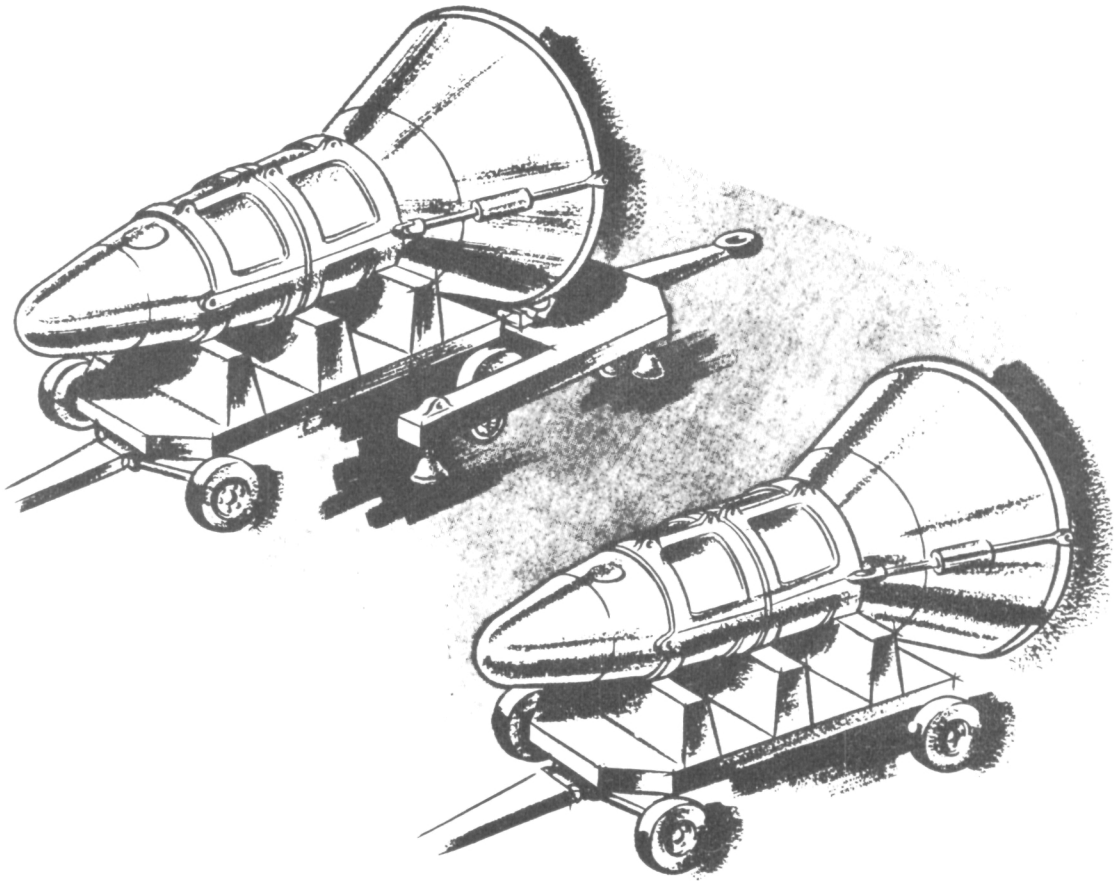

Figure I-10-B/I-10-14. Vehicle Assembly/Disassembly Equipment

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During the sctual booster tests, all one-shot devices, less explosives, will be used. This test will confirm over-all vehicle and booster compatibility using internal power. All of the recorded data received during the tests will be sent to the hangar area for reduction and analysis. At the completion of the booster tests, the vehicle will be disassembled from the booster, lowered from the gantry, mounted on the transport vehicle, and returned to the hangar.

10.2.5 Field Hangar-Final Checkout

Upon returning to the hangar following the flight readiness tests, an inspection will be conducted on all subsystems. Equipment will be provided in the hangar area for all requirements of maintenance and disassembly of the APOLLO Vehicle down to the black-box component level. Following the inspection, leakage tests on the APOLLO Vehicle plumbing and cabin areas will be repeated. Any leaks found at this time will be carefully investigated to determine the cause of the leak, and to insure that it will not recur under actual launch conditions. After these final preparations, a final hangar confidence test will be conducted using the Vehicle Checkout Console and the Electronic Subsystem Test Set. The APOLLO Vehicle will then be transported to the Explosives Installation Area.

10.2.6 Explosives Installation Area

The APOLLO Vehicle will be transported from the hangar to the explosives installation area (Figure I-10-15) for installation of any explosive devices and live rockets, and for performing any other operations which are considered to be a hazard to personnel safety by the Range Safety Office. Confidence checks will be made which include applying electrical power to the APOLLO Vehicle, insuring compatibility with the explosives installed. During this procedure, the transport vehicle will be suitably braced or tied down to prevent movement in case of accidental rocket ignition. After satisfactory completion of tests, the APOLLO Vehicle will be transported to the launch pad with all safety circuits suitably monitored.

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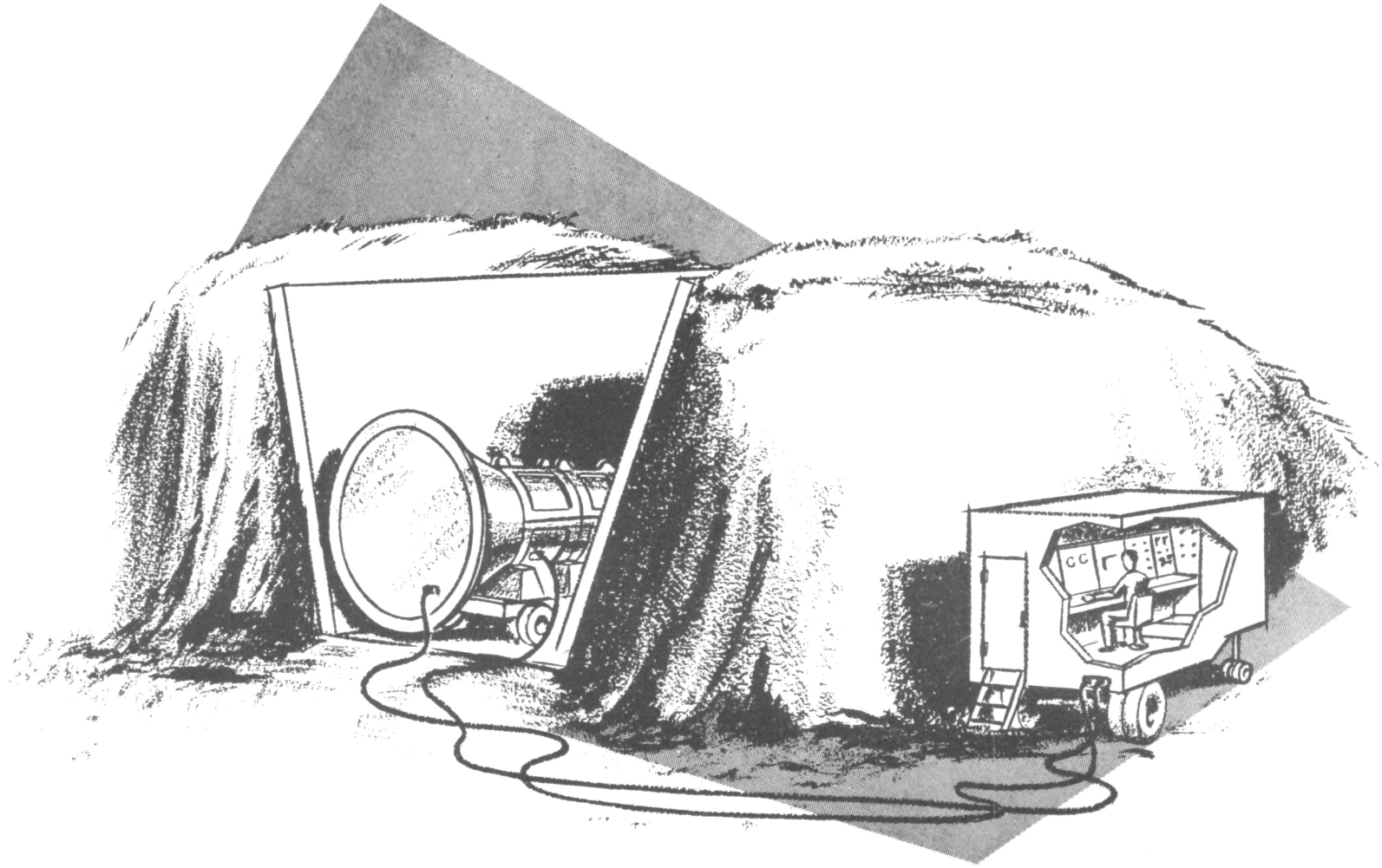

Figure I-10-15. Explosive installation area

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10.2.7 Launch Pad-Launch Operation

At the launch pad, the APOLLO Vehicle will be vertically mated to the booster with the same procedure and in the same sequence as was followed for the flight readiness tests. All ground servicing units will be connected to the vehicle. Countdown is initiated. External power will be applied through the ground power system and, with the Operating Console and Electronic Subsystem Test Set, a test crew will conduct the operations in the cabin area and check all visual displays.

This will include:

a. Check of crew's control and instrument panels.

b. Confidence checks of all subsystems.

c. Checkout of the instrumentation and communication subsystem via open loop transmission.

d. Monitoring of all explosive and rocket firing circuits.

The space vehicle is then readied for the flight crew. With the flight crew in the vehicle, the countdown is continued to launch.

Following missile "lift off" from the launch pad, the monitoring and command functions will be transferred to the APOLLO Control Center at the Atlantic Missile Range. To facilitate quick observation of the APOLLO Vehicle performance, a Post Launch Monitoring Set will be provided to be used in conjunction with the telemetry receiving equipment at the Control Center.

10.3 RECOVERY PLAN AND EQUIPMENT

The landing phase of an APOLLO mission will be either normal, abort, or contingent in nature. Touchdown potential, therefore, exists for a diverse combination of locations and conditions and, as such, all areas will necessarily have to be considered when evolving and implementing the search and recovery procedure. Possibilities include:

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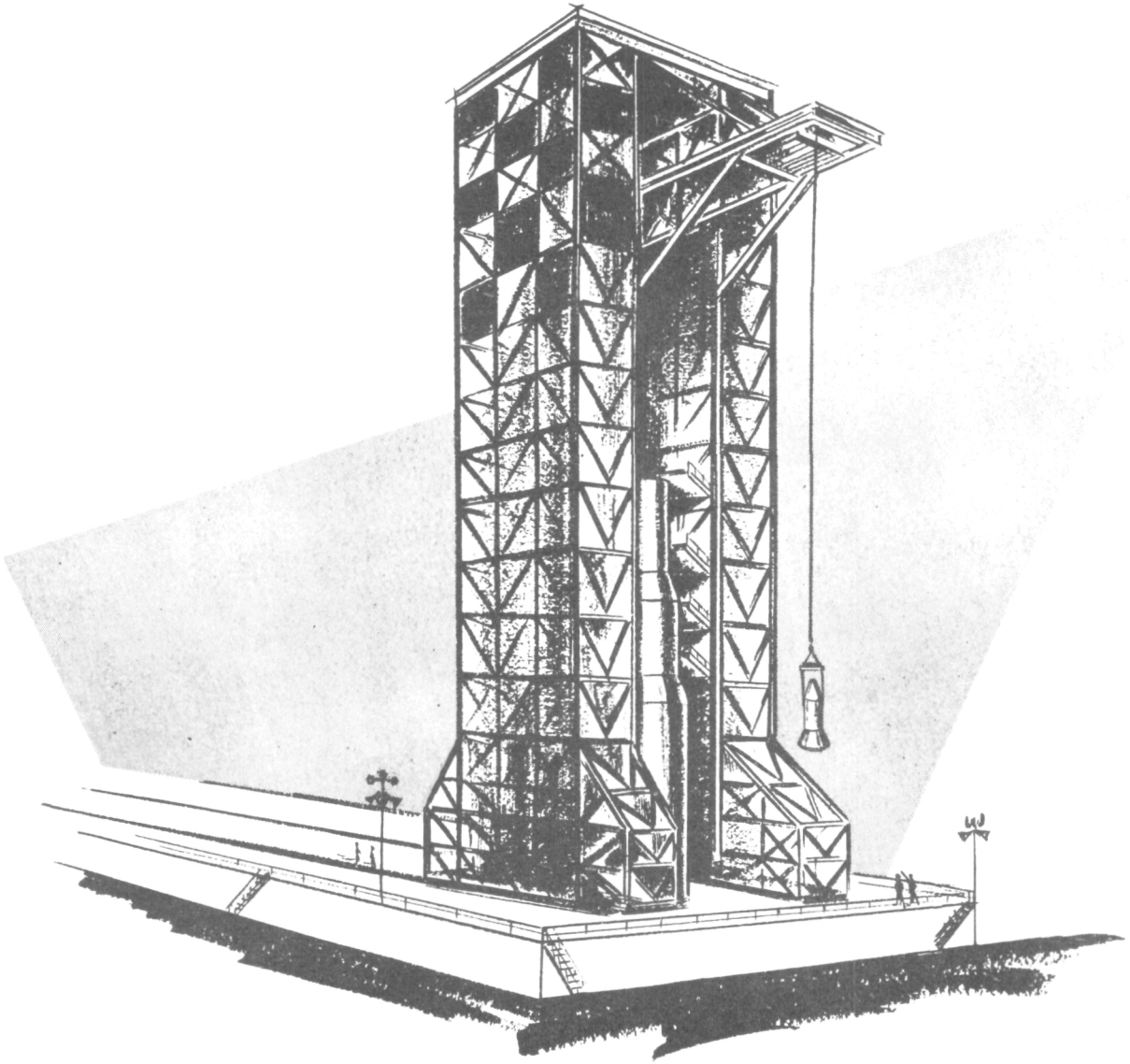

Figure I-10-16. Vehicle-to-missile mating

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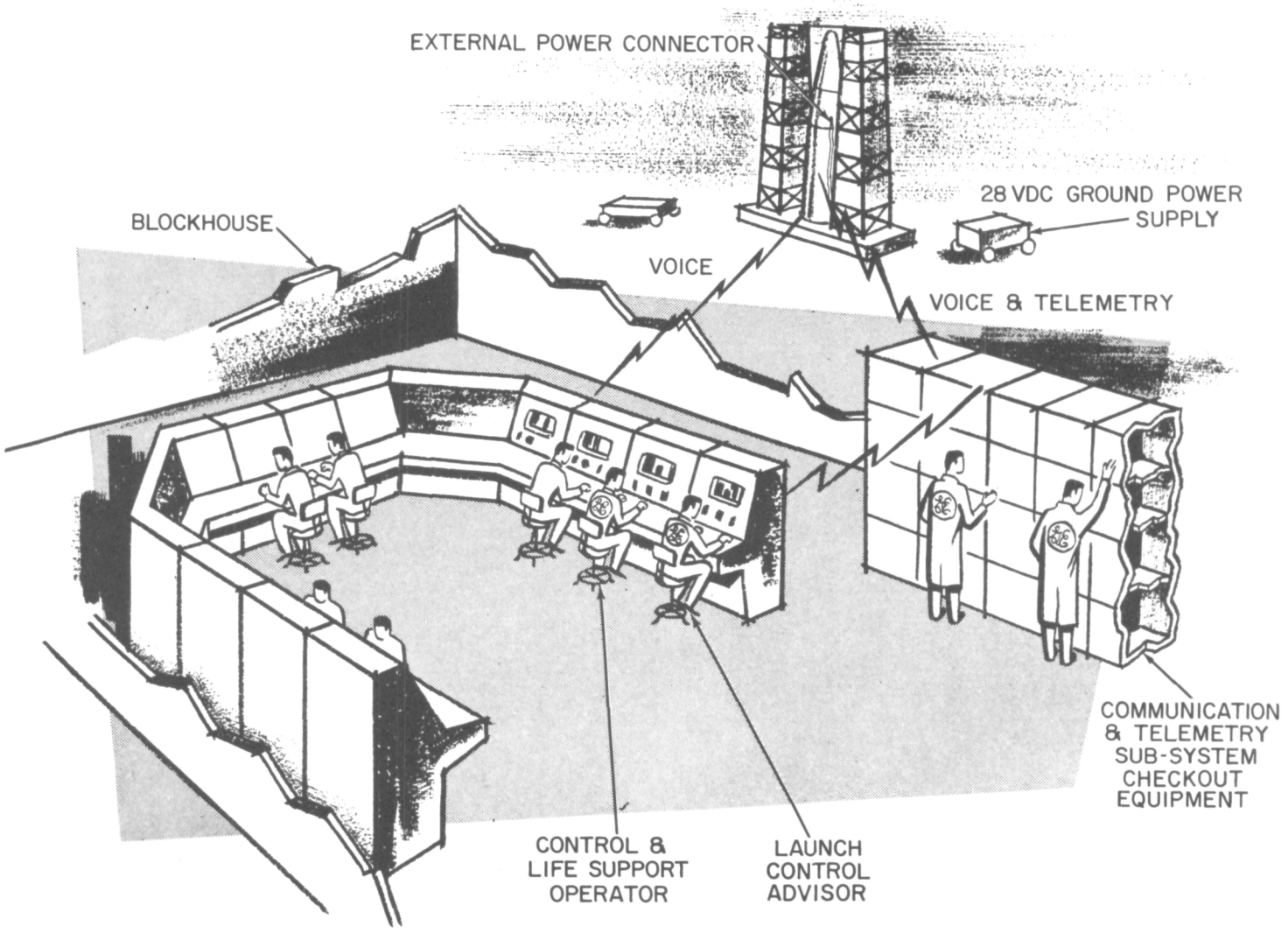

Figure I-10-17. Launch site

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a. Primary prepared ground landing site

b. Secondary prepared ground landing site

c. Unprepared ground landing site (Mountainous terrains, crevices, cliff-side, high altitude plateau, swamps or marshes, snow or glaciers, and jungles).

d. Calm sea (waves 6 ft. max.)

e. Heavy sea (anything over 6 ft. waves)

Coupled with these possibilities is any crew and/or re-entry vehicle disability which must be factored into the situation.

It is felt that the following recovery procedures and equipment possess the highest degree of feasibility and probability of success, and implementation will proceed accordingly.

10.3.1 Primary Prepared Ground Landing Site

Crew and data removal would be effected immediately via helicopter while re-entry vehicle retrieval and transport could be done in relative leisure. Eventually, a hoist equipped helicopter would attach to the re-entry vehicle pick-up fitting and transport the entire assembly to the operations area. At this point a handling rig would be attached to the original re-entry vehicle mounting hard points. A portable crane/load balancer could then be utilized to lift the assembly and place it on a portable handling stand.

10.3.2 Secondary Prepared Ground Landing Sites

The requirements and procedures for these facilities will be the same as those for the primary installations.

10.3.3 Unprepared Ground Landing Sites

Generally, a landing resulting from some contingency inherently possesses a higher probability for personnel injury and/or vehicle damage. Therefore, not only is the vehicle located in a potentially awkward, inaccessible area, but little or no active help may be forthcoming from its occupants to aid in their recovery.

The tracking-communication-computer link will provide forewarning of deviation from the planned impact area. Long range search aircraft, in ready status, would be dispatched to the predicted impact area. A search pattern would be flown and, upon locating the re-entry vehicle, the situation would be appraised via communication and/or visually.

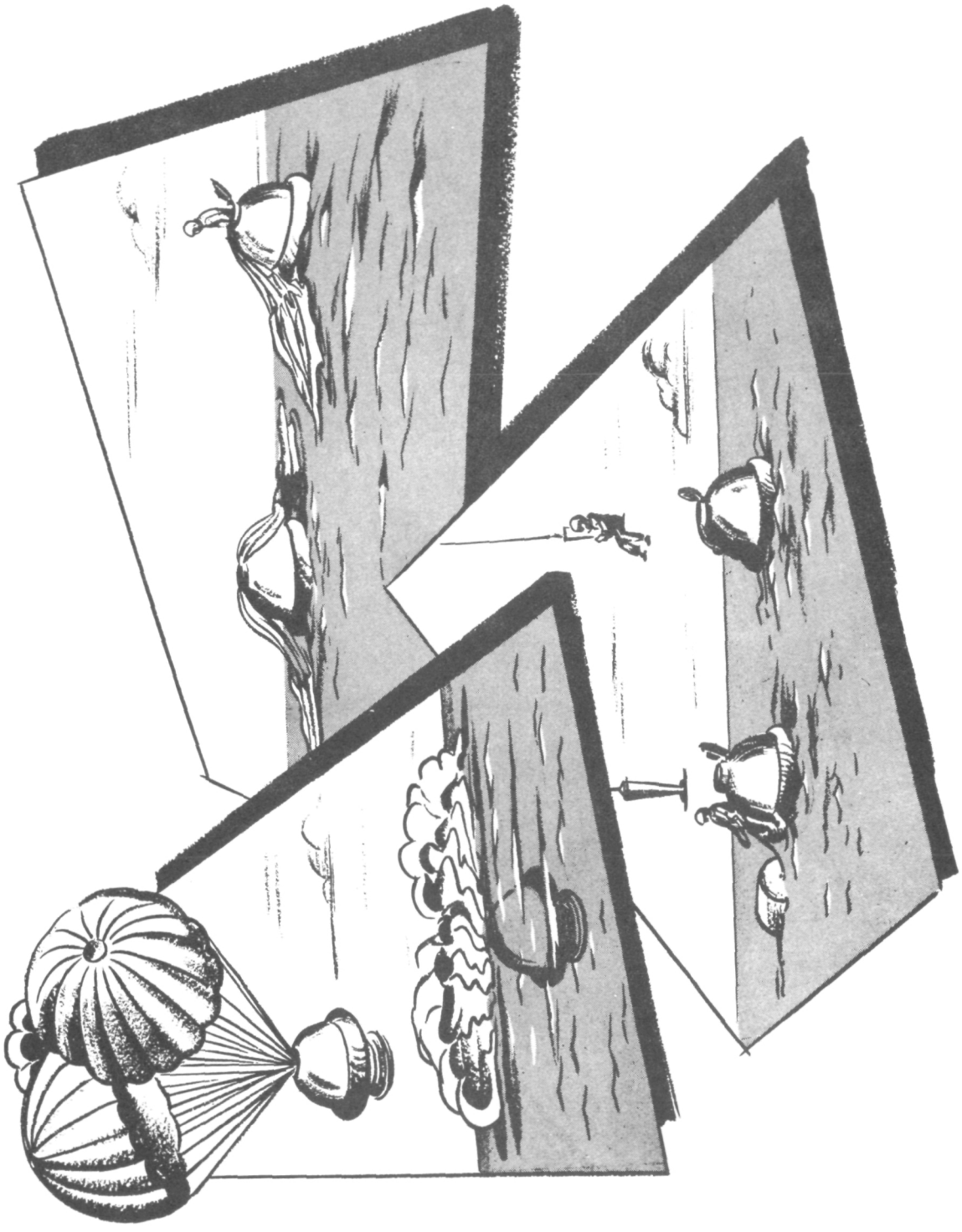
Supplies and supplementary equipment would be dropped; paramedics may or may not be utilized depending upon circumstances.

Crew, data, and vehicle will be removed in that order with prime emphasis devoted to the crew and then the data. The demonstrated versatility of helicopters makes them ideally suited to usage for this application.

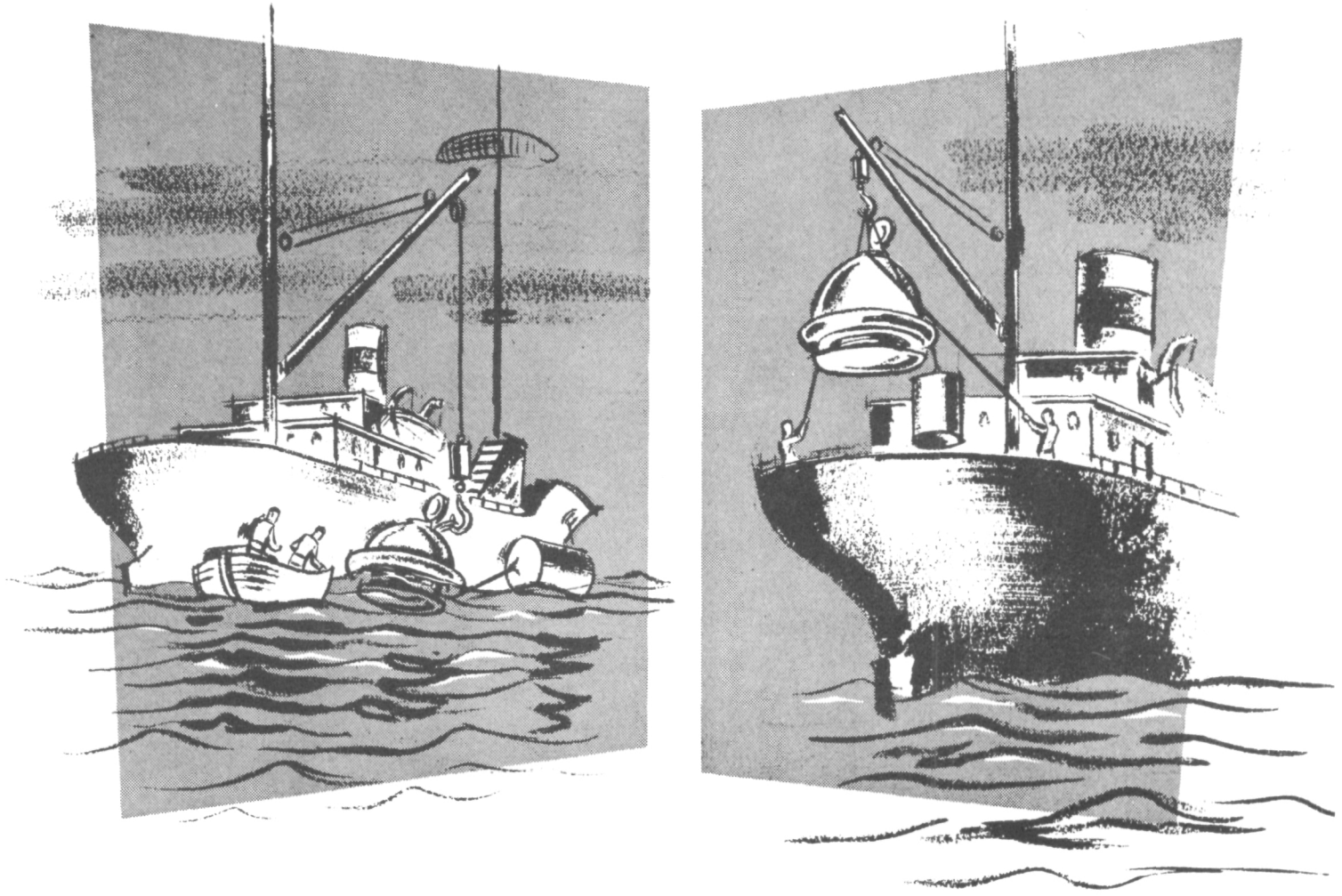
10.3.4 Calm Sea Recovery

Figures I-10-18 to I-10-25 depict the sea recovery techniques to be employed for the APOLLO Command Module. Search aircraft, upon locating the vehicle, would maintain surveillance and direct rescue activity to the area. Search helicopters would immediately commence rescue operation. Astronauts and data would first be removed by means of a hoist-sling/seat arrangement. Vehicle recovery would then be initiated. The procedure involved could be similar to that successfully employed by GE-MSVD in the recovery of nose cones.

A back-up flotation buoy would be lowered into the water and attached to the re-entry vehicle by a helicopter crewman, who would also deactivate any pyrotechnic devices. A surface ship would "heave to" in the area and lower a powered whale boat over the



Figures I-10-18/I-10-19/I-10-20. Landing and recovery equipment



Figures I-10-21/I-10-22. APOLLO Sea Recovery Equipment

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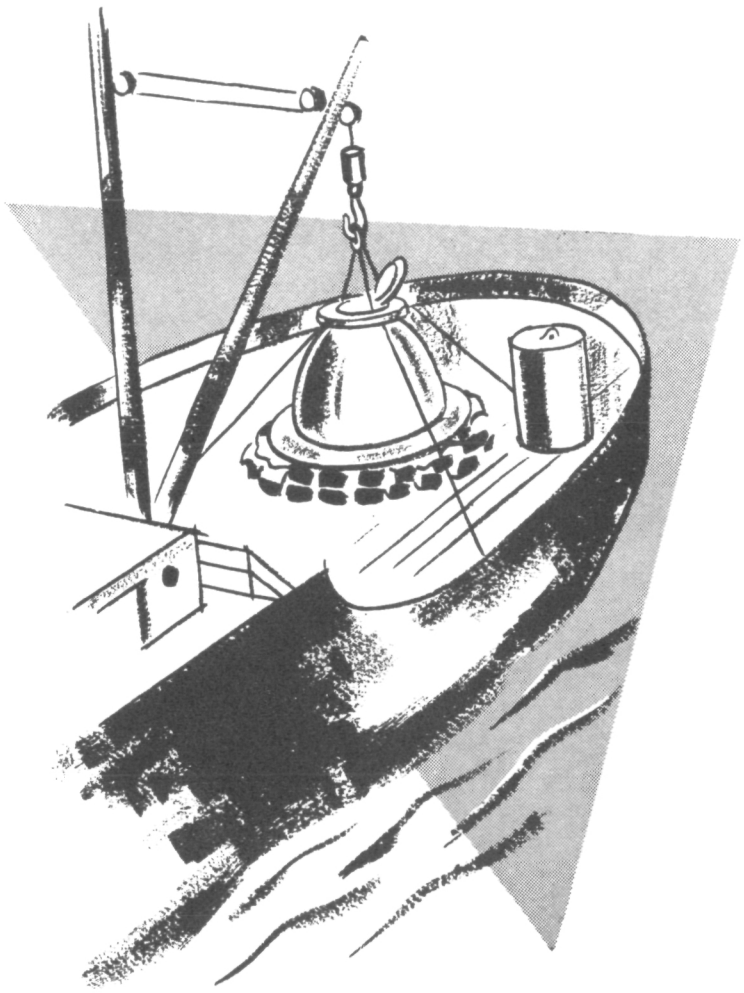

Figure I-10-23. APOLLO Sea Recovery Equipment

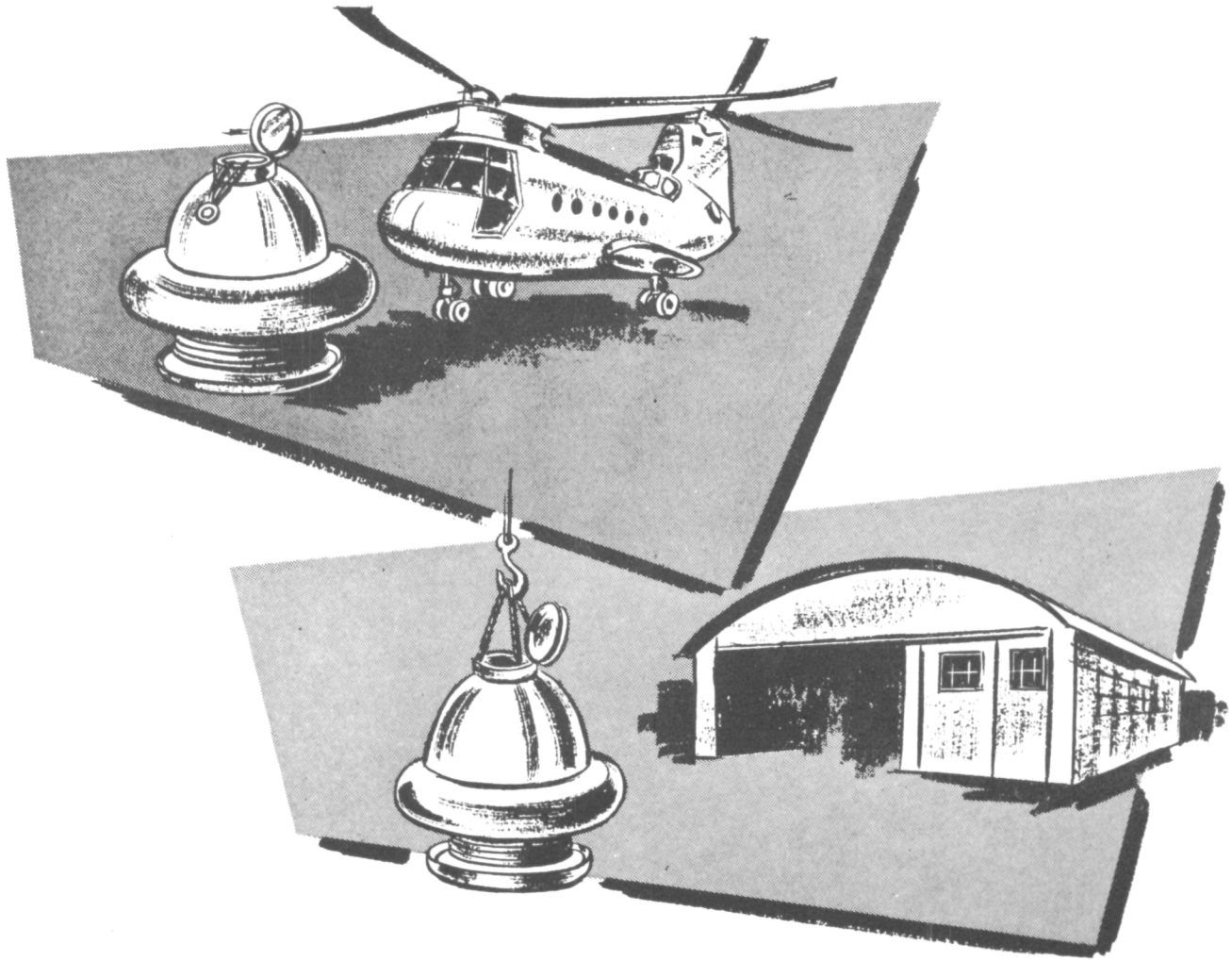

Figure I-10-24/I-10-25. APOLLO Land and Sea Recovery Equipment

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side. Crewmen working from the small boat would attach steadying lines to the re-entry vehicle and connect the ship's boom-load balancer combination to the capsule pick-up fitting. The assembly would then be hoisted out of the water and directed over the deck where the steadying lines would be manned by deck hands. The vehicle would then be lowered onto a sandbag cushion where, with partial tension maintained in the boom cable, the buoy is removed and a handling ring is attached to the original re-entry vehicle mounting hard points. The boom would then lift the assembly and place it on a stand which could be lashed to the deck.

10.3.5 Heavy Sea Recovery

The same general search and recovery techniques would be carried out as for the calm sea state. However, participation of certain units and consequent results will be directly proportional to the degree of prevailing natural violence - high wind, clouds, rain, waves, etc.

10.3.6 Helicopters

These vehicles are proven workhorses of a rescue mission. Although there are problems involved in their use, sufficient operational experience has been gained to insure a high reliability in recovery operations. They would provide the fastest recovery of crew and data and under some of the conditions delineated above, would afford a practical, safe method of recovering crew, data, or capsule. Several classes of these machines appear likely for consideration and currently available data for them is included in Table I-10-I.

10.4 FIELD FACILITIES PLAN

10.4.1 General

The primary needs of the APOLLO system dictate a requirement for ground support facilities under four general categories as related to system operations, i.e.:

TABLE I-10-I

HELICOPTERS BEING CONSIDERED FOR USE IN APOLLO RECOVERY

Model Designation	Manu - facturer	Speed	Range	Load	Accommodations
H-25/HUP-2**	Vertol	80 mph (cruise)	340 miles	400 lbs.	4 passengers or 3 stretchers
H-21**	Vertol	98 mph (cruise)	115 miles	3,000 lbs.	20 passengers
107 YHC-1B*	Vertol	160 mph (max.)	240 miles	6,000 lbs.	
S-56/H-37/HR 23*	Sikorsky	125 mph (cruise)	200 miles	7,000 lbs.	36 troops or 24 stretchers
HSS-1/HUS-1**	Sikorsky	98 mph (cruise)	280 miles	3,000 lbs.	12 - 18 troops
S-61/HSS-2/HRS-2	Sikorsky			6,000 lbs.	
S-64*	Sikorsky	109 mph (cruise)	320 miles 200 miles	5,000 lbs. 10,000 lbs.	

* Recommended for Crew Recovery Only.
**Recommended for APOLLO Vehicle and Crew Recovery.

a) Prelaunch and launch

b) Control, tracking and communications

c) Recovery

d) Geodetic

10.4.2 Prelaunch and Launch Facilities

10.4.2.1 PRELAUNCH BUILDING

a) General

The use of existing buildings at Cape Canaveral in which prelaunch functions could be accomplished was investigated. All buildings capable of being utilized for this purpose are either in use for other programs or do not provide the required space for Project APOLLO operations.

It is proposed to erect a new Prelaunch Building in the industrial area of Cape Canaveral (see Figure I-10-26) adjacent to the Saturn Assembly Building. By locating the Prelaunch Building in this area, greater accessibility will be provided to the Saturn booster facilities. This may prove to be advantageous since there is a possibility that installation of Saturn payloads may eventually be accomplished in the Saturn Assembly Building. In addition, the Saturn docking facilities on the Banana River will be available for use in the immediate vicinity.

b) Construction

The APOLLO Prelaunch Building will be a mill-type structure with a high center bay and low one-story structures on either side, as shown in Figure I-10-27. The structure consists of a steel frame with metal skin roof and siding, and the roof of the high bay supported on trusses spaced 20 feet on center.

The doors on both ends of the high bay area should be designed to provide maximum exclusion of dust, dirt and other exterior contaminants. Some of the functions to be performed in the building include:

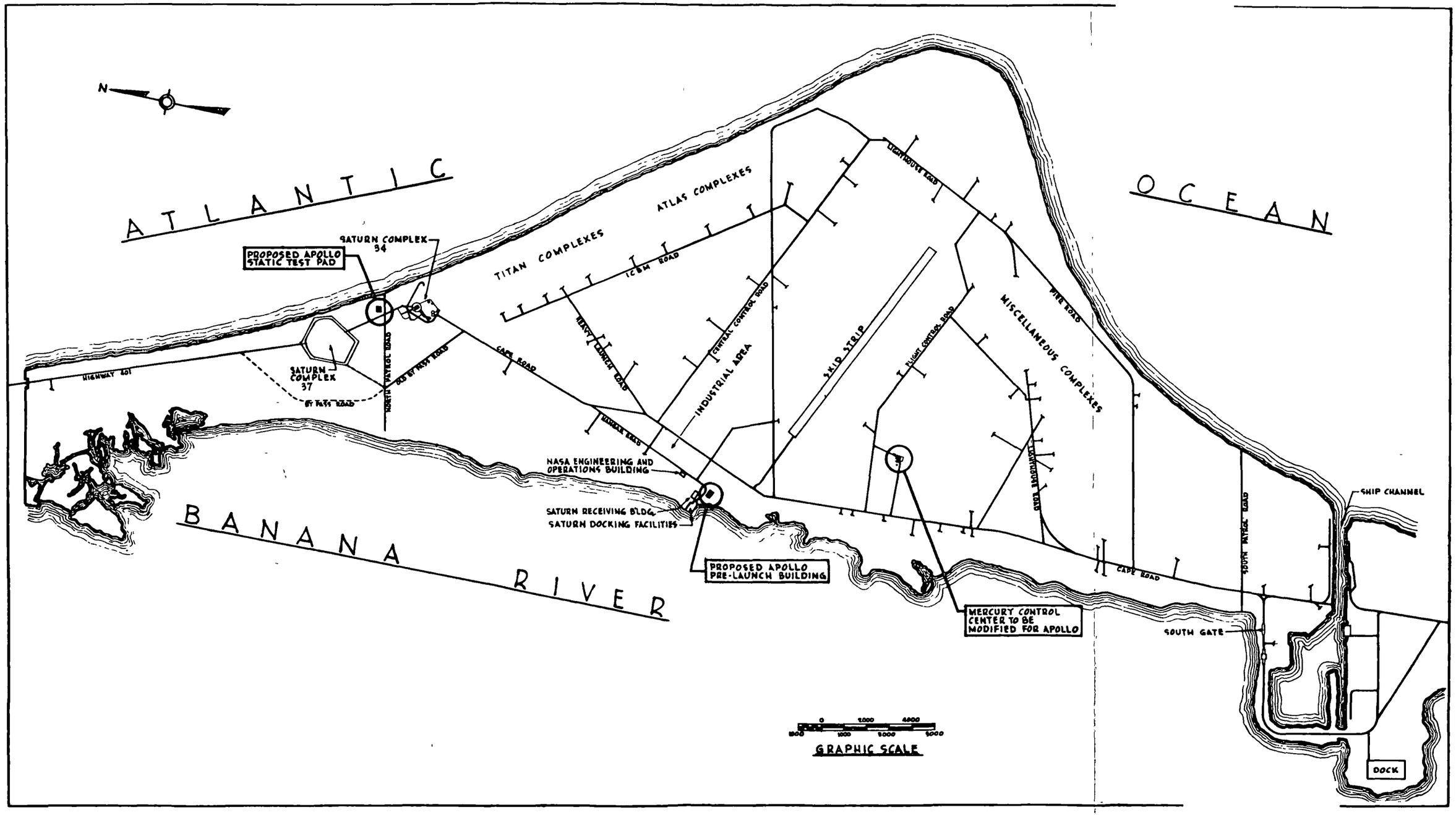
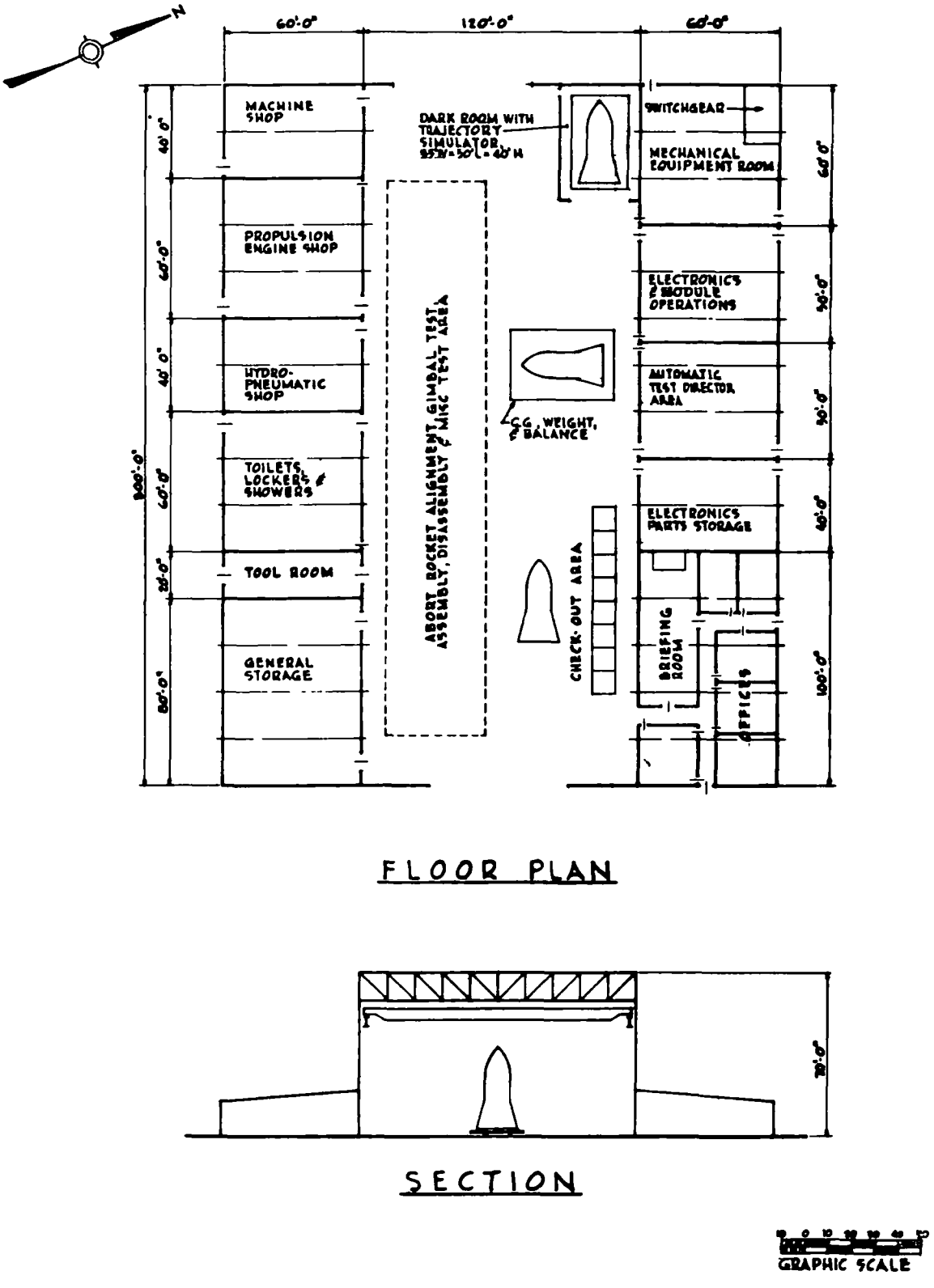


Figure I-10-26. AFMTC Cape Canaveral



FLOOR PLAN

SECTION

Figure I-10-27. Pre-launch building, plan and section

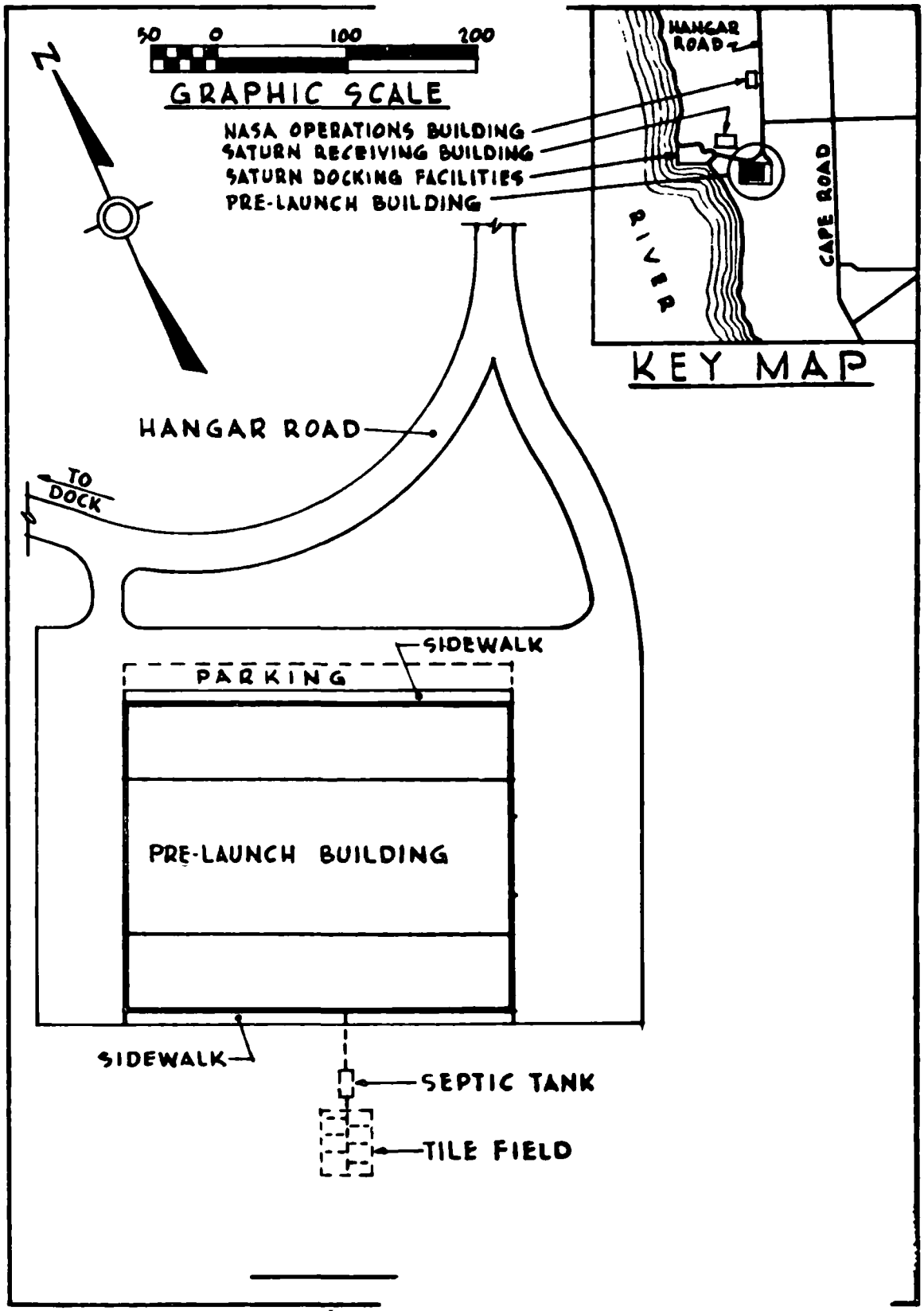


Figure I-10-28. Pre-launch area
Cape Canaveral, site plan

1) Assembly and disassembly of vehicle.

2) Receiving and storage of parts.

3) Testing of parts.

4) Servicing.

5) Checkout of subassemblies and of the assembled vehicle.

The high center bay will house a bridge crane spanning the full width of the bay, which will provide sufficient headroom to handle the assembled vehicle during all operations called for in the checkout and testing procedures.

The low, one-story portion of the building on each side of the high bay will be utilized for shops, offices, briefing rooms, storage, toilets, lockers, etc.

The determination of foundation design for a building of this size must await detailed analysis of column loadings and soil borings. It is expected, however, that the foundation will require a slab on piles due to the proximity of the building to water and expected high column loading. The building floor slab should also contain necessary covered trench networks to provide for distribution of compressed gases, electrical power and electronic cables.

c) Utilities

Electrical utility power supply can be obtained by tapping into the Air Force Missile Test Center's 13,200-volt, 3-phase utility distribution system at a point near the Prelaunch Building. A transformer will be used to reduce the voltage from 13,200 to 480 volts with distribution to the 480-volt loads through low-voltage circuit breakers and combination motor starters. Four transformers will be used to further step down the voltage from 480 to 120/208 volts, 3-phase, 4 wire for lighting and other single-phase loads to minimize voltage drop.

Motor-generator equipment powered from the 480-volt bus will be used to provide 28-volt direct current and 400-cycle power as required.

The electronic supply for the building will be obtained from the Air Force Missile Testing Center's 13,200-volt, 3-phase electronic power system near the building site. This "electronic power" is specially regulated 60-cycle electric power furnished for electronic equipment which is sensitive to voltage and frequency variations and must be reliable. A transformer will be used to reduce the voltage from 13,200 volts to 120/208 volts, 3-phase, 4 wire, with distribution to the electronic loads through voltage circuit breakers.

A proposed arrangement for the Prelaunch Building utility and electronic power distribution systems is shown in Figure I-10-29.

Electrical and electronic cable and wiring runs in the high bay area and electronic equipment rooms should be in covered floor trenches to minimize interference and provide ease of accessibility. Wiring and cable distribution in other areas can be via overhead cable ladders or buried conduit.

Air conditioning is required for satisfactory operation of equipment, cleanliness and preservation of parts, and efficiency of operation. The environmental conditions of the Electronics and Module Operations, Computer Programming, Electronics Parts Storage and Office areas will be automatically controlled at all times. The high bay area and other areas of the building will be ventilated and heated.

A central air conditioning unit will be located in the Mechanical Equipment Room. The schematic for the system is shown in Figure I-10-30. Approximately 40 tons of refrigeration will be required, with blower and duct systems distributing air to the conditioned areas.

The Electronics and Module Operations Room should be designed as a "white room." A special high-efficiency filter will be provided in the air supply to this room to

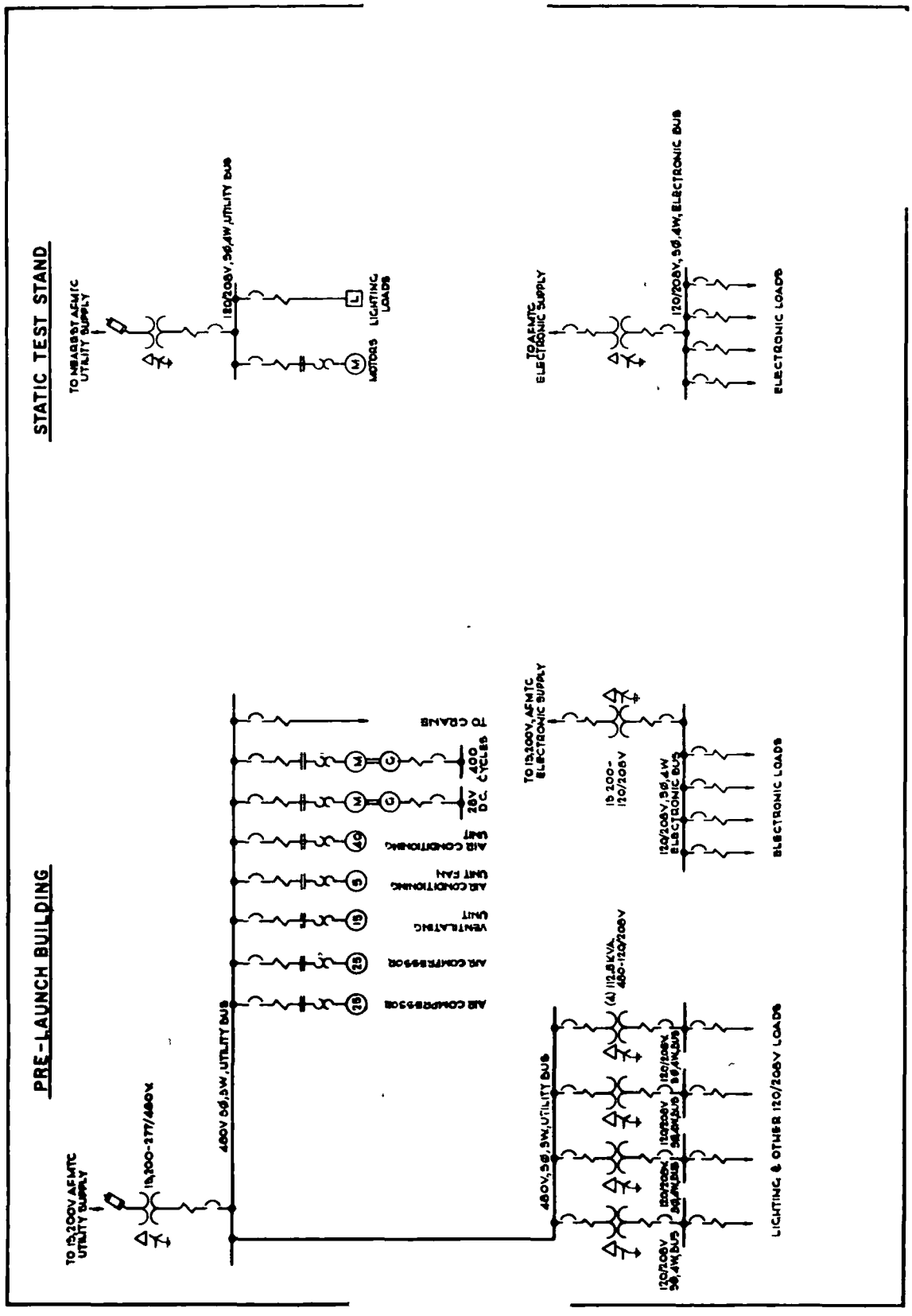
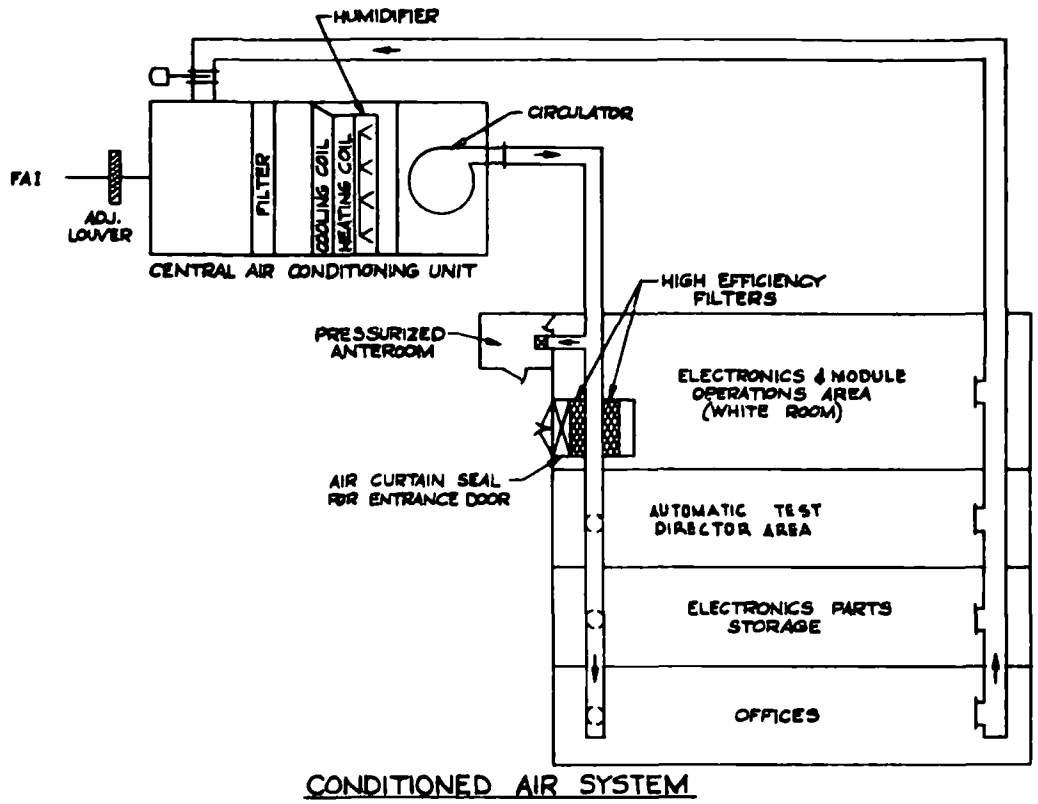


Figure I-10-29. Pre-launch building and static test stand Electrical one line diagram



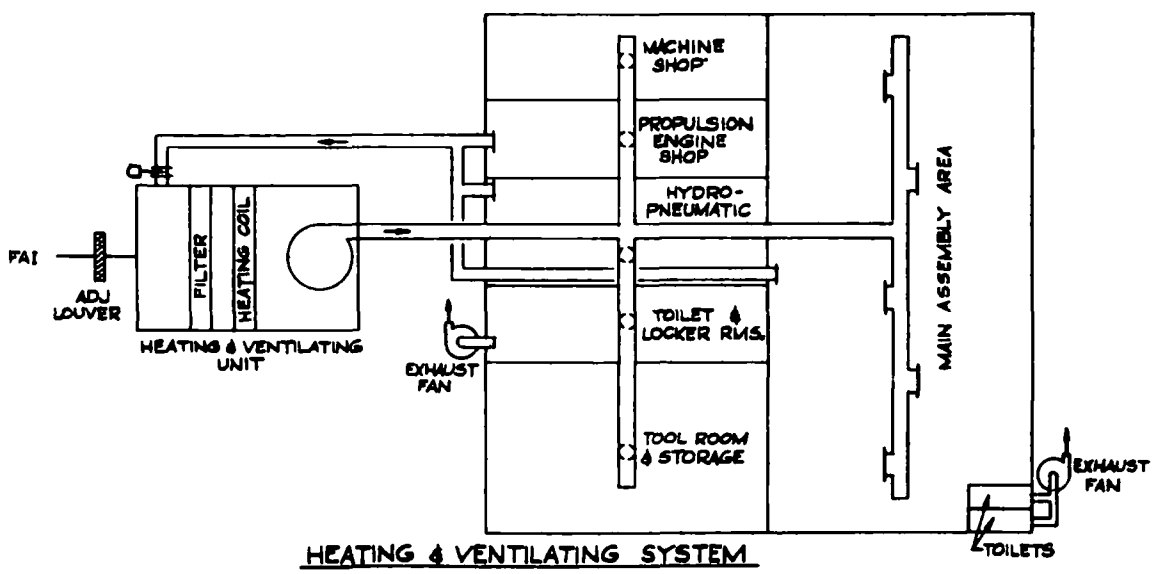


Figure I-10-30. Pre-launch building-air conditioning diagrams

maintain a dust free atmosphere, together with a pressurized antechamber with two self-locking and interlocked doors for personnel entrance. Space for changing clothes will be provided in this chamber. Operations should be performed by employees in non-linting clothes and covered shoes. An air curtain will be provided to seal the large door openings and to minimize room contamination when they are opened. Positive pressure will be maintained in the room to assure that contaminants are not introduced into the area. The relative humidity in the area will be maintained between 45-50 percent. The interiors of this area should have all sharp edges eliminated, all joints covered and all surfaces finished with nondusting materials.

All air-conditioned areas will be maintained at an ambient condition of 75 degrees F dry bulb and 50 percent relative humidity, unless equipment requirements dictate other limitations.

Ventilation will be provided in all other areas of the building and a positive pressure maintained within the building. A minimum of 15 cfm fresh air per person will be provided. All practicable provisions to keep the inside of the building free from dust, dirt and excessive noise should be made.

A hot water heater and circulating system will be required for sanitary and heating requirements.

A cooling tower, located adjacent to the building, will provide cooling water for the air conditioning condensers, air compressors, and the water cooling requirements of other equipment.

Two air compressors and a storage receiver will be provided for service and shop air. An automatic dual-tower chemical drying unit will be required to furnish dry, clean air to each area. High-pressure nitrogen and helium storage bottles will be located outside the Mechanical Equipment Room and the gases will be distributed

to all areas for purging and blowing out tanks and capsule compartments, and testing for leaks in the vehicle.

Toilet facilities will be provided in shop and office areas with hot and cold water supplied to fixtures as required. A septic tank and tile field will be provided to handle sanitary waste.

A water connection will be run from the existing base fire main to supply a hydrant fire protection system on the outside of the building and a standpipe system on the inside. Portable fire extinguishers will also be provided in each area.

10.4.2.2 STATIC TEST STAND

a) General

The Static Test Facility will be designed to test the vehicle propulsion system at sea-level conditions after assembly and checkout in the Prelaunch Building. Simulation of starting and firing under high-altitude conditions is not required, since it is understood that such tests will be conducted at test facilities of the propulsion system manufacturer. The installation will consist of a thrust stand as shown in Figure I-10-31 for firing vehicles in the horizontal position, propellant and high-pressure gas storage and transfer facilities, and instrumentation and controls.

Consideration was given to locating the Static Test Stand closer to the prelaunch facility to reduce the transportation and handling time. However, this would be objectionable in a populated area due to the high noise levels generated by the engine during a test. In addition, the danger of fuel and cryogenic fluid storage and use in such areas would conflict with existing range safety requirements. The orientation of the thrust stand, as well as its location, is selected to minimize the noise and accidental explosion problems at adjacent working areas, and to direct acoustic effects and combustion products seaward. With this location, it is possible that testing operations will have to be suspended while fueling or launch

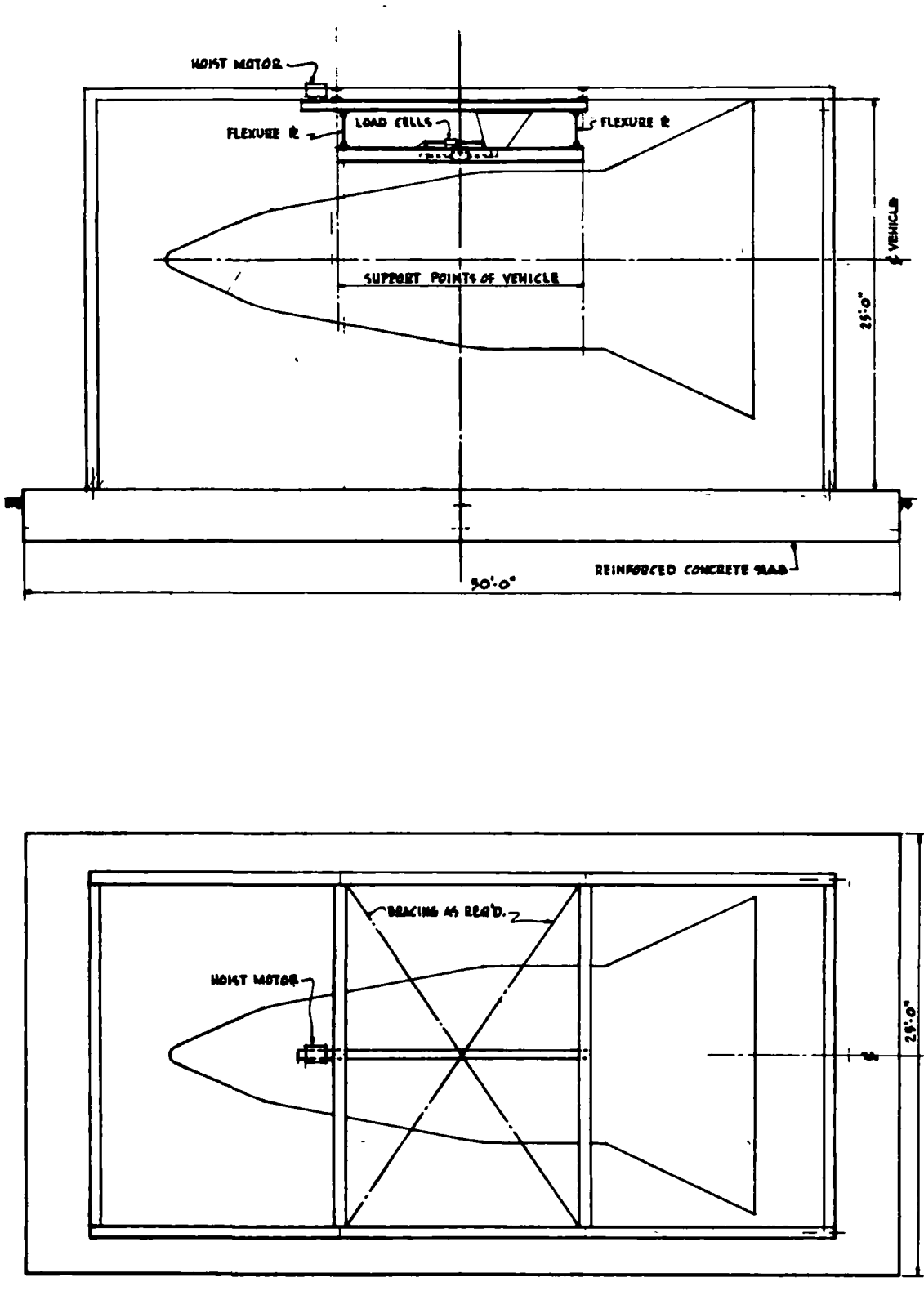


Figure I-10-31. Static test stand
Plan and elevation

operations are in progress at Complexes 34 and 37. This may result in a 24-hour delay in static firing, but is not considered a serious limitation at this time.

b) Construction

Since the propulsion system for the APOLLO vehicle is presently rated at 25, 000-pounds thrust, the Static Test Stand will be designed for a maximum thrust of 50, 000 pounds to allow for future engine power growth. See Figure I-10-32 for location and arrangement.

The stand will be an open steel structure on a reinforced concrete slab, on which the vehicle is suspended from an overhead support. Although not included at this time, it will be a relatively easy matter to add a sun and rain shield in the future if it is found that climatic conditions hamper operations. A bed-type thrust stand was considered, but this type of stand would not be as convenient to operate since it would be less accessible and more difficult to maintain than the overhead type. The vehicle will be transported to the stand in its transport dolly, lifted off the dolly by the hoist and clamped to the thrust frame. The thrust measuring structure will include stainless-steel flexure straps, or a similar strain member, in a fixed steel structure. Measuring and calibrating load cells will be provided in order to ascertain eccentricity in thrust development. Instruments and controls for measuring and recording data will be located in a control van located adjacent to the thrust stand.

c) Servicing Systems

In the development of the fuel supply system, the possibility of fueling directly from tank trucks was considered. However, if fuel delivery is not available when required or transportation delays are encountered, the availability of the facility would be reduced and program schedules compromised. Therefore, liquid oxygen and liquid hydrogen storage facilities will be provided at the installation to fuel the vehicle as shown in Figure I-10-33.

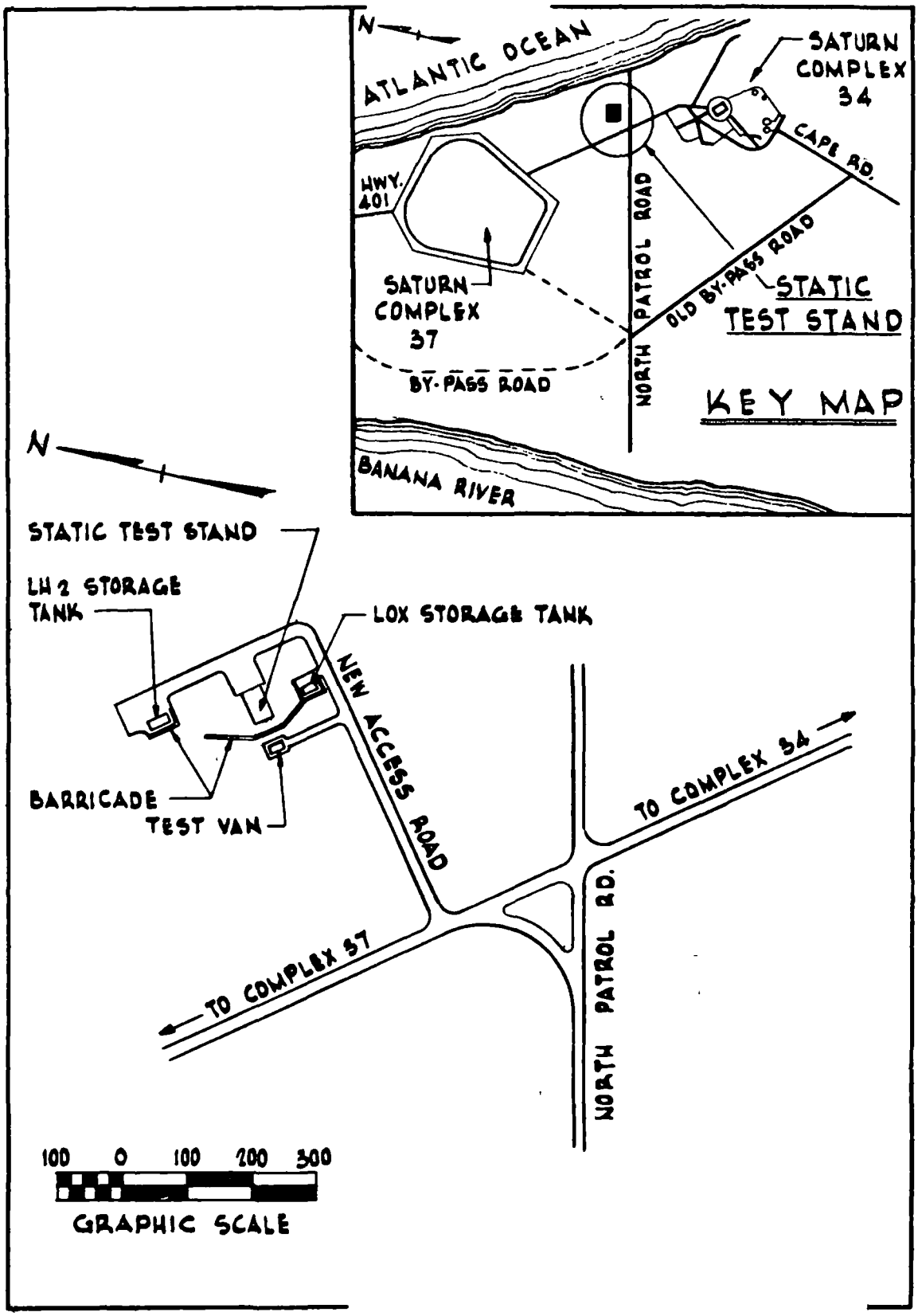


Figure I-10-32. Launch area
Cape Canaveral, site plan

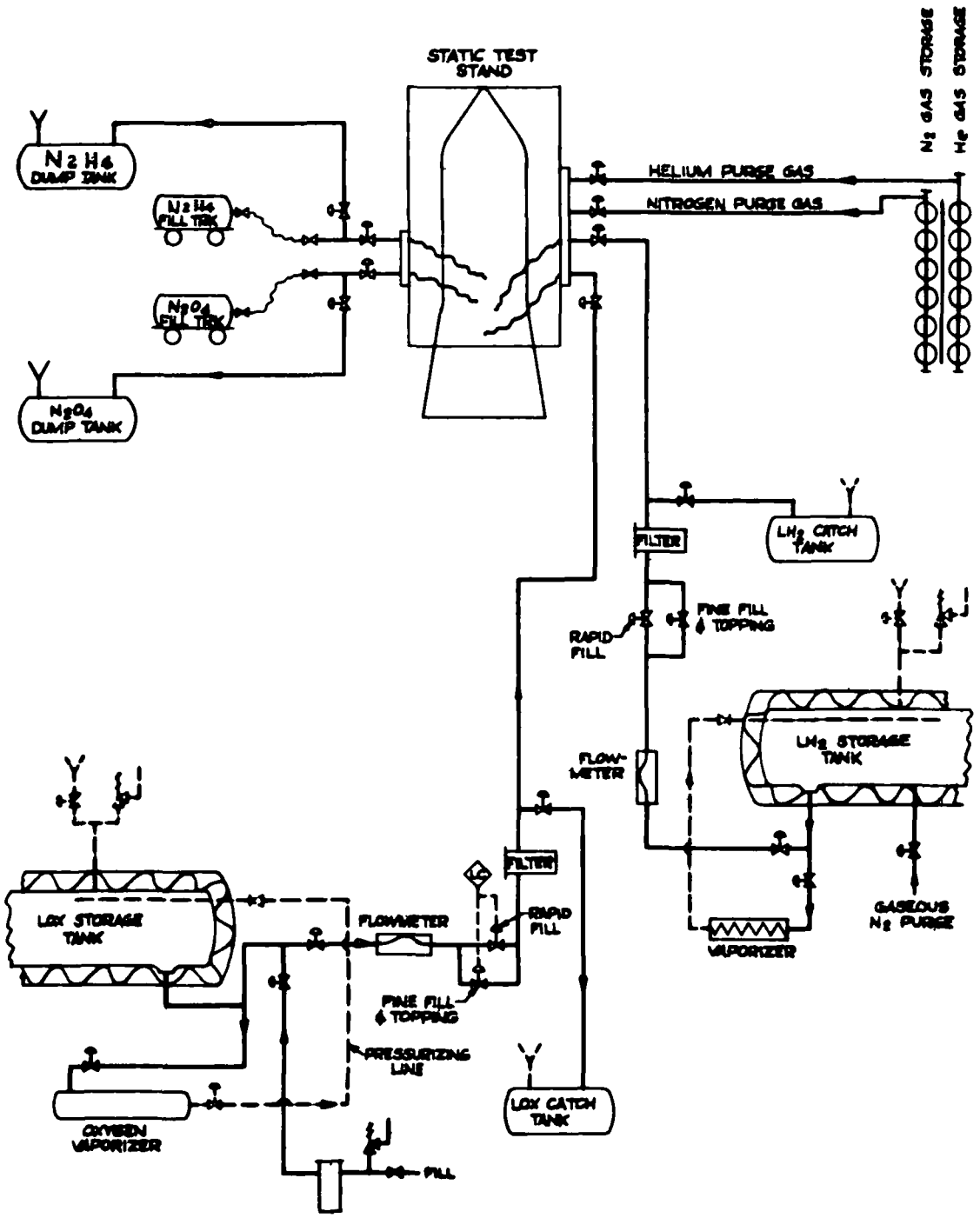


Figure I-10-33. Static test stand - fuel diagram

Storage of propellants will be provided for two test runs and for pressurizing the tanks for propellant transfer to the vehicle. A 750-gallon Lox Dewar storage tank and a 2500-gallon liquid hydrogen Dewar storage tank will be located approximately 500 feet from the test stand. The Dewars will have a stainless-steel inside shell and aluminum outside shell and will be powder- and vacuum-insulated. A vaporizer system will be provided to transfer the propellants from storage tanks to vehicle storage. Controls will be provided to measure and control level of fluid in tanks.

A dike will be provided around each storage vessel to contain fluid in case of leak. Earth barricades will be required around each storage area as well as between test stand and the main road to provide protection to personnel and vehicles in the area or on adjacent roads in the event of a fuel explosion. Relief valves, rupture discs and other protective devices will be furnished as required.

Nitrogen and helium gas bottles will be located behind the earth barricade with connecting pipelines to the test stand for purging the vehicle and cryogenic systems before and after a test. Connections will be provided to allow fuel service trailers to deliver nitrogen tetroxide and hydrazine to the test stand for fueling of vehicle tanks, since permanent storage is not provided for these fluids.

A connection panel will be mounted on the thrust stand for conveniently making all piping, wiring and control connections to the vehicle. Permanent connections from the connection panel to stationary facilities will minimize the number of connections to be made for each test. Instrumentation and controls will be provided from a service van located behind a barricade. Permanent connections between the van location and the test stand connection panel will be provided.

d) Utilities

The Static Test Facility can be supplied with electric utility power from nearest utility power supply using a transformer to step down the voltage to 120/208-volt, 3-phase, 4-wire power for lighting and other small loads.

Electronic power from the nearest electronic power supply will be stepped down to 120/208 volts, 3-phase, 4-wire for feeding the electronic equipment in the service van. A service power panel will be required adjacent to the van location for connecting power cables to the equipment van.

10.4.2.3 LAUNCH INSTALLATIONS

a) General

Since Saturn boosters will be used for launching the APOLLO payload, the effect of APOLLO system requirements on the Saturn launch complex facilities has been investigated. Complexes 34 and 37 Saturn facilities are scheduled to be completed in time for the APOLLO payload tests and, based on proposed launch schedules, will be generally adequate for the vehicle requirements, except as herein noted.

If off-complex facilities are required for assembly of vehicle and booster, it is assumed that these facilities will be similar to those at the Saturn launch complex and will be adequate for the APOLLO vehicle.

It is planned to make mating checks, final calibration and ground transmission checks, leak and functional checks for the APOLLO vehicle from an Electronic Subsystem Test Set in a ground support van. External power will be available from existing 28-volt d-c and 400-cycle power supplies.

b) Service Gantry

Since it is planned to install the APOLLO vehicle on the Saturn booster at the launching pad, the Saturn service gantry will be used to lift the vehicle in this operation.

Based on the information available, the Complex 34 Saturn service gantry will have a usable short lead hook height of 245 feet. Since the combined height of the Saturn

booster and the APOLLO vehicle will be less than 210 feet, there will be no need for major modifications to the service gantry. Both the major and the minor hooks on the gantry will be capable of supporting a load far in excess of the APOLLO vehicle weight. It is assumed that the Complex 37 service gantry will be designed with at least equal capabilities.

c) Umbilical Tower

The servicing lines to the vehicle will be routed through the umbilical towers provided for Complexes 34 and 37. Supply lines for liquid oxygen, hydrogen and nitrogen, gaseous nitrogen, helium, nitrogen tetroxide, hydrazine, as well as pneumatic and electrical instrumentation lines will be routed through the umbilical tower to the payload via the topmost umbilical arm.

d) Servicing Systems

Cooling and purging of the propellant tanks, the cabin area and cooling of electronic and other gear will be accomplished from GSE vans. Liquid nitrogen facilities being provided at the Saturn complexes will be available if required.

It is assumed that fueling of the vehicle with liquid oxygen and fuel will be accomplished at approximately the same time as the Saturn fueling. Planned installations for these fluids will be adequate for the APOLLO fill and topping requirements. The Lox and liquid hydrogen fill and topping system will be automatic and will be initiated and controlled from the blockhouse propellant loading panels.

Separate storage facilities and servicing systems for the APOLLO vehicle were considered, but the additional cost for such redundant installations would be difficult to justify and would not offer any operating advantages.

It is understood that breathing oxygen will be installed in the vehicle in precharged tanks, and nitrogen tetroxide and hydrazine will be supplied to the vehicle storage

tanks from fuel service trailers. Therefore, ground systems will not be required for these services.

e) Escape System

The problem of personnel escape from the APOLLO vehicle presents conditions which have not previously been encountered. The fact that the vehicle will be more than 200 feet from ground level makes an effective and reliable escape system a prerequisite for minimum personnel safety.

The umbilical towers and gantries at Complexes 34 and 37 will require minor modifications to allow for installation of a "high line" personnel escape system from the APOLLO vehicle.

It is proposed to install this "high line" system between a boom from the umbilical tower to a lower-level gantry servicing platform. With the gantry tower in the withdrawn position, this will provide means of emergency escape for vehicle personnel via the vertical man-lift on the gantry tower and the escape tunnel in case of fire, fuel leaks, or other noncatastrophic-type conditions. A concept layout of this system is presented in Figure I-10-34.

Although the proposed escape system is obviously conceptual only, and has not been subjected to detailed study and design investigation, it is thought that it presents the possibility of a reliable and practical means of emergency escape from the vehicle.

Together with the "high line" concept, many other solutions have been considered, such as helicopter evacuation, umbilical elevator, "cherry-picker" type equipment, and "high line" to the ocean or remote areas around the launch complex. However, each of these possibilities presents limitations of either excessive escape time, insufficient safety margins, impractical design problems, excessive cost factors, or various combinations thereof.

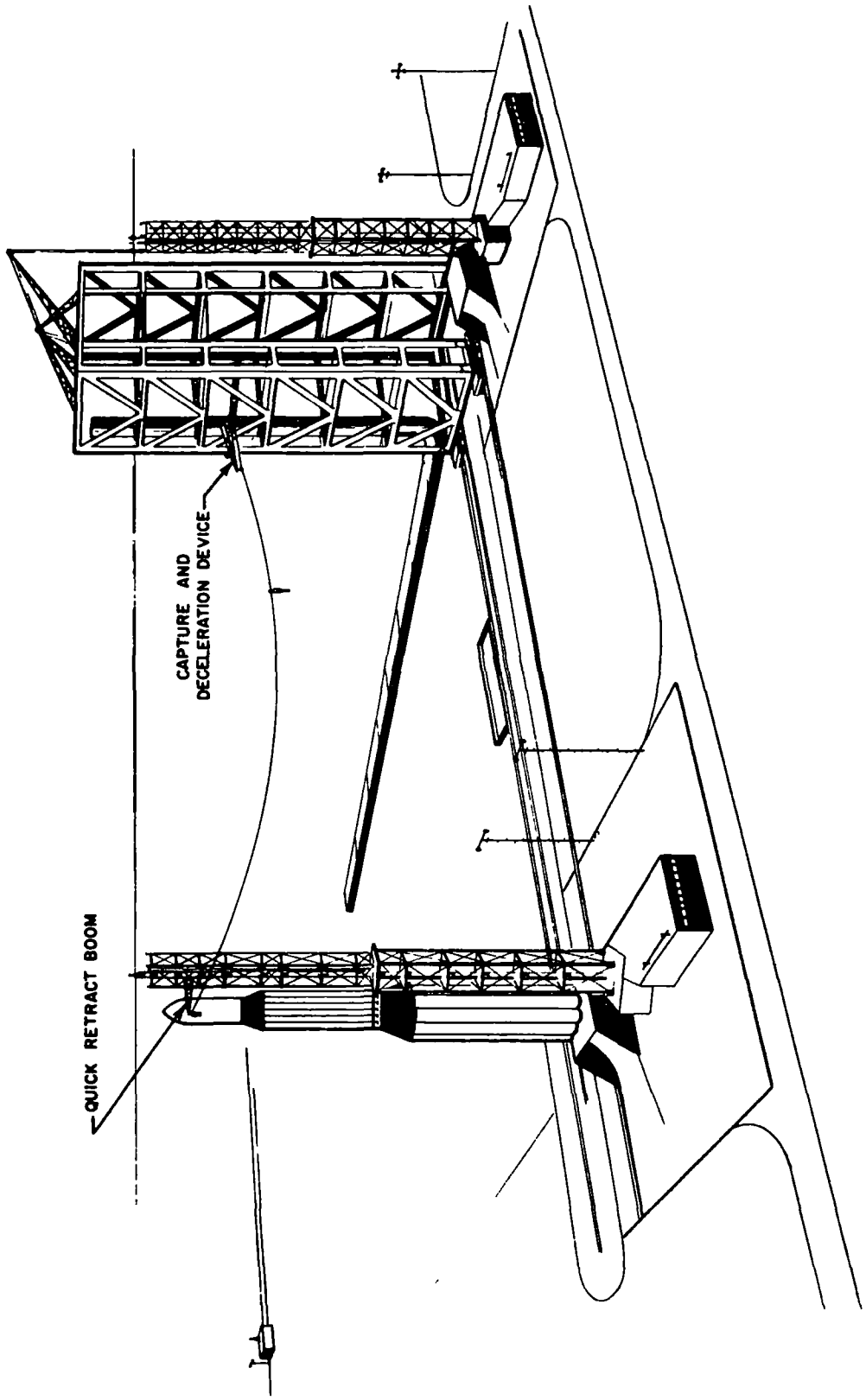


Figure I-10-34. Launch area - escape system

An analysis of all concepts considered indicates that the "high line" system shown in Figure I-10-34 will provide reasonable safety assurances for vehicle flight personnel with the least probable modification and installation cost and fullest utilization of existing installations.

10.4.3 Control, Tracking and Communications Facilities

10.4.3.1 CONTROL CENTER

a) General

The requirement for a Control Center at Cape Canaveral for Project APOLLO made necessary an investigation to determine whether construction of a new facility would be justified. It was determined that the existing Mercury Control Center would be functionally capable of Project APOLLO support with increased Control Room and Trainer Room space. An economic evaluation of the problem indicates that the construction of a new facility, with costly duplication of many supporting areas of the building, could not be justified.

To adapt the Mercury Control Center to Project APOLLO requirements, building modifications will be limited to enlarging the Control Room Area, the Trainer Area and the Mechanical Room, as shown on Figure I-10-35.

b) Control Areas

The Control Area will be enlarged to approximately twice its present size to accommodate a world map, space trajectory plot and other equipment. It first appeared that the extension of this area to the northeast would be the most logical approach to gain the maximum reuse of existing construction. However, the existing row of columns on the northeast side of the control area must be removed, since it is essential that the operating personnel have an unobstructed view of both the world plot and the trajectory plot, as well as all other sources of vital data in the control area. A more detailed study of the building design indicated that the removal of these columns is at variance with proper structural design

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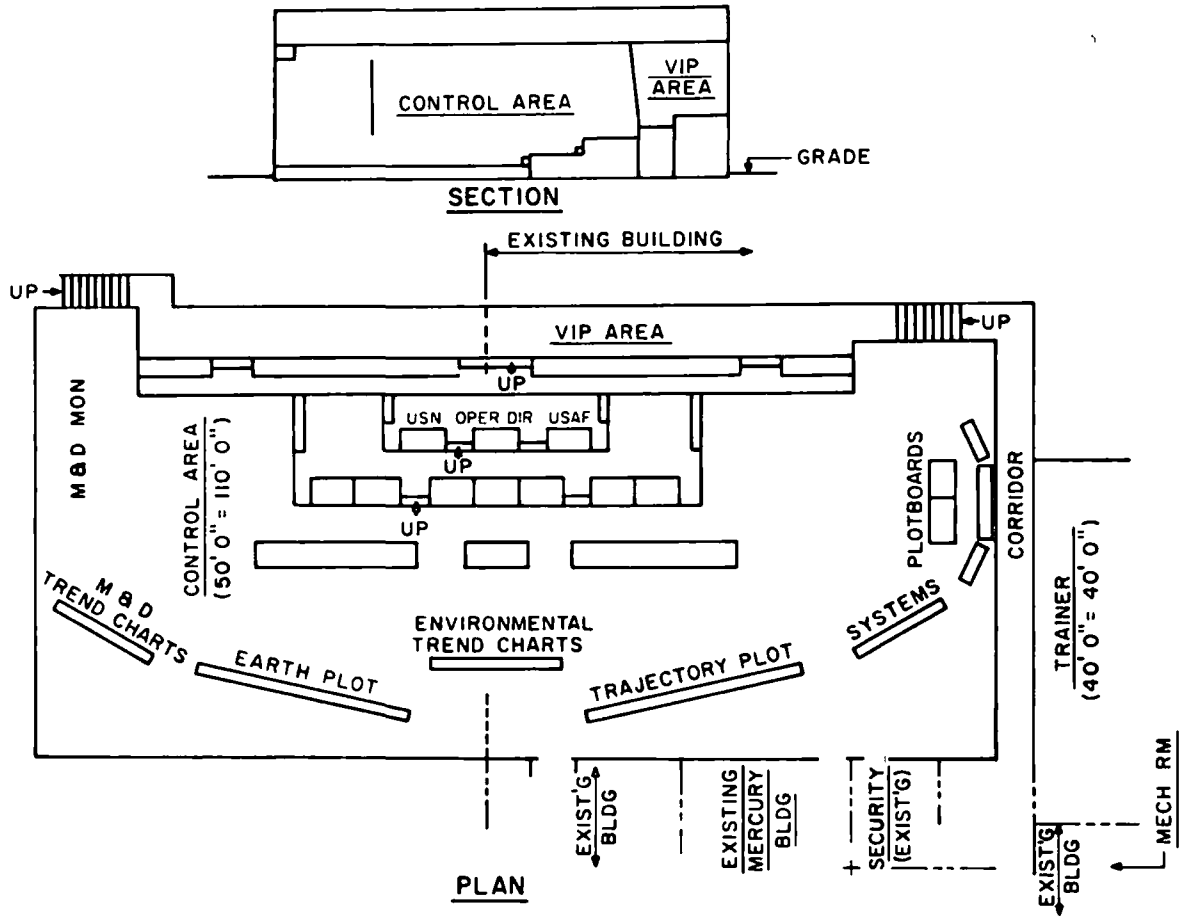

Figure I-10-35. APOLLO control center - Cape Canaveral

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practice. When modifying an existing building, every effort should be made to avoid any changes which would alter the original, basic design concept of the structure. In addition, modification of the reinforced concrete, rigid framed bents would require the following:

1) Temporary shoring of roof beams within the existing control area.

2) Cutting and removing existing columns.

3) Removing existing spread footings, together with portions of existing raised floor and slab.

4) Pouring new footings, columns and girders to support the existing roof beams plus the roof beams for the new addition.

An alternate solution which would eliminate these disadvantages and provide required floor space with a minimum of structural changes to the building is the extension of the Control Room area in a northwest direction. This will require only the removal of curtain walls, extension of existing building construction and rearrangement of the interior, as shown in Figure I-10-35, and is preferable from a design and cost standpoint.

c) Trainer Area

The room used as the Trainer Area for Project Mercury will probably not be large enough to perform the same functions for the APOLLO program. A room approximately twice this size is required. It is proposed to build a 40-foot by 40-foot extension to the existing building east of the existing control area. This room will require a 40-foot clear span in each direction for unobstructed floor space, and will necessitate a deviation from the 20-foot column spacing used in the original building design.

d) Mechanical Room

The existing Mechanical Room does not contain space for the additional air conditioning equipment required by the increased facilities. Since the

location of the existing Mechanical Room adjacent to the access road and the parking field precludes its enlargement, a new utility room will be located in the present Mercury Trainer Area. This central location will result in shorter duct runs and a more efficient installation with a negligible amount of structural changes.

It should be noted that, throughout all of the proposed modifications, design, materials and finishes will be kept consistent with the presently installed facility.

e) Utilities

Modification of the existing Mercury Control Center for APOLLO operations and the resultant increase in floor areas to accommodate proposed APOLLO equipment will require approximately 30 kw of additional lighting. This added lighting load can be fed from spare circuit breakers in an existing 120/208-volt power panel in the Control Center.

A new air conditioning unit with a 40-hp motor will be required to furnish air conditioning for the new Control Area and Trainer Room. Power for this unit can be fed from the 480-volt bus and the existing 90-ampere trip main circuit breaker replaced with one of 225-ampere trip rating.

Any additional electronic equipment required in the APOLLO Control Center will be fed from a spare 125-ampere circuit breaker in an existing 120/208-volt electronic panel. Since 125 amperes represents about 30 kilowatts of power input to electronic equipment, it is assumed this supply will be ample for any additional electronic equipment required in the APOLLO Control Center.

The proposed changes in the existing buses in the Control Center to accommodate the APOLLO loads are shown in Figure I-10-36.

The Control and Trainer Rooms must be air conditioned for satisfactory operation of the equipment located in these areas and, in view of the functions to be performed, for comfort of the personnel. These areas in the Mercury Center are

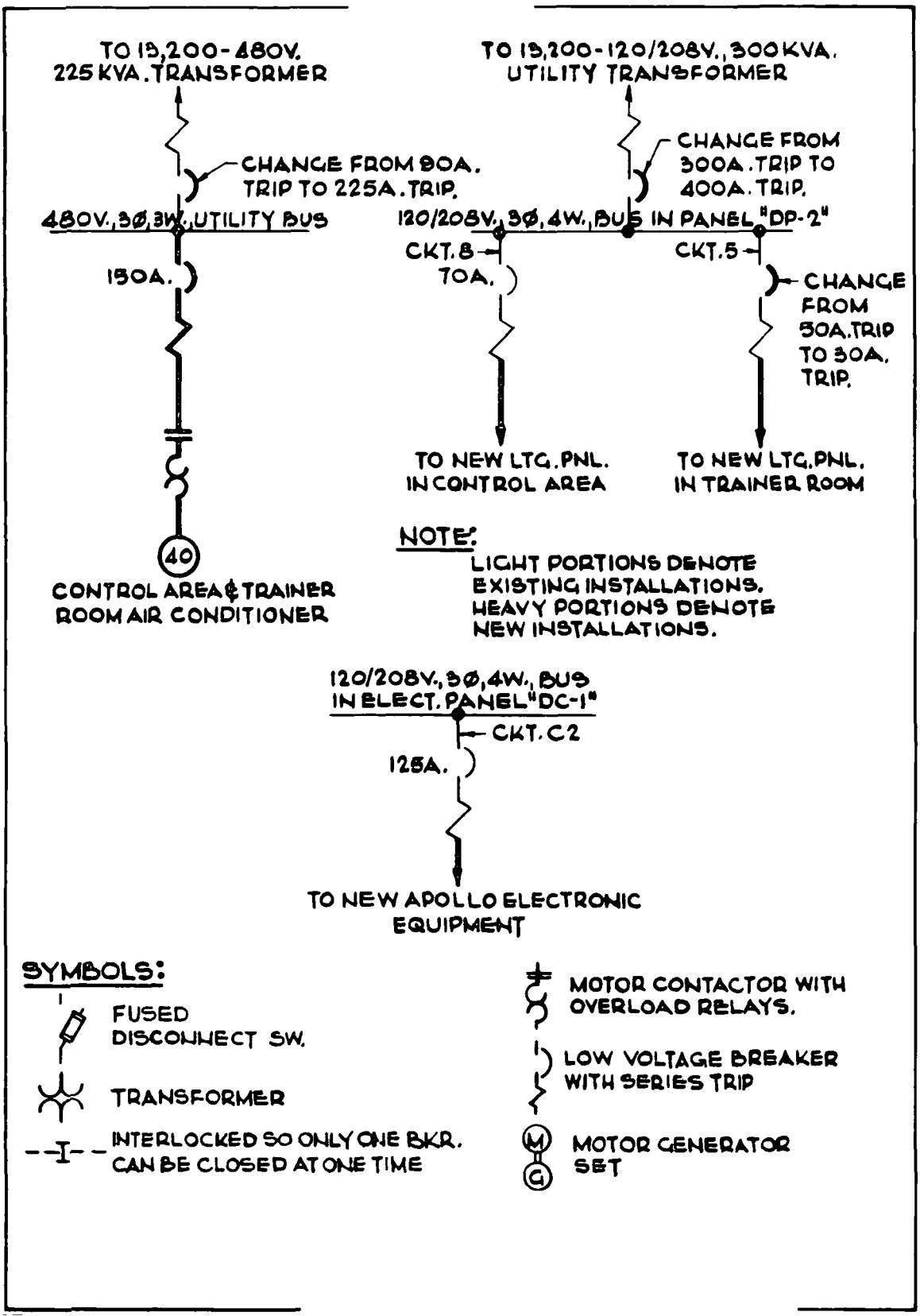

Figure I-10-36. Control center - electrical one line diagram

now air conditioned, but the cooling and air handling capacity of the existing equipment is already marginal. Additional capacity will be required for the enlarged areas.

Consideration was given to providing only the additional capacities required to meet the requirements for the new areas and loads to be added. However, it is considered preferable to size the new equipment for the whole area to obtain better distribution and control of air temperatures and humidity. A packaged system capable of providing approximately 40 tons of refrigeration will be required.

The existing air handling units for these areas will become spares, or used for other purposes. A ductwork system will be used to distribute the air to these areas using existing ductwork wherever possible. The system will be designed to maintain ambient conditions at 75 degrees F dry blub and 50 percent relative humidity, unless equipment requirements dictate other limitations.

Existing hot water heating capacity, potable water and sanitary facilities appear to be adequate and no modifications are contemplated.

f) Displays

Since the flight path contains three dimensional elements, rather than only positional elements based on a constant altitude trajectory, the initial basic requirement is to display the required data. For this purpose an x-y, y-z plotting board is placed alongside the existing earth track plotting board. (Some modifications must be made to the existing earth plotting board.) The new board displays the vehicular position data with respect to the earth's equatorial plane in a form in which the actual versus planned trajectory is shown. Such a plotting board is illustrated in Figure I-10-37.

The remaining new telemetry displays are separated into four main areas of interest:

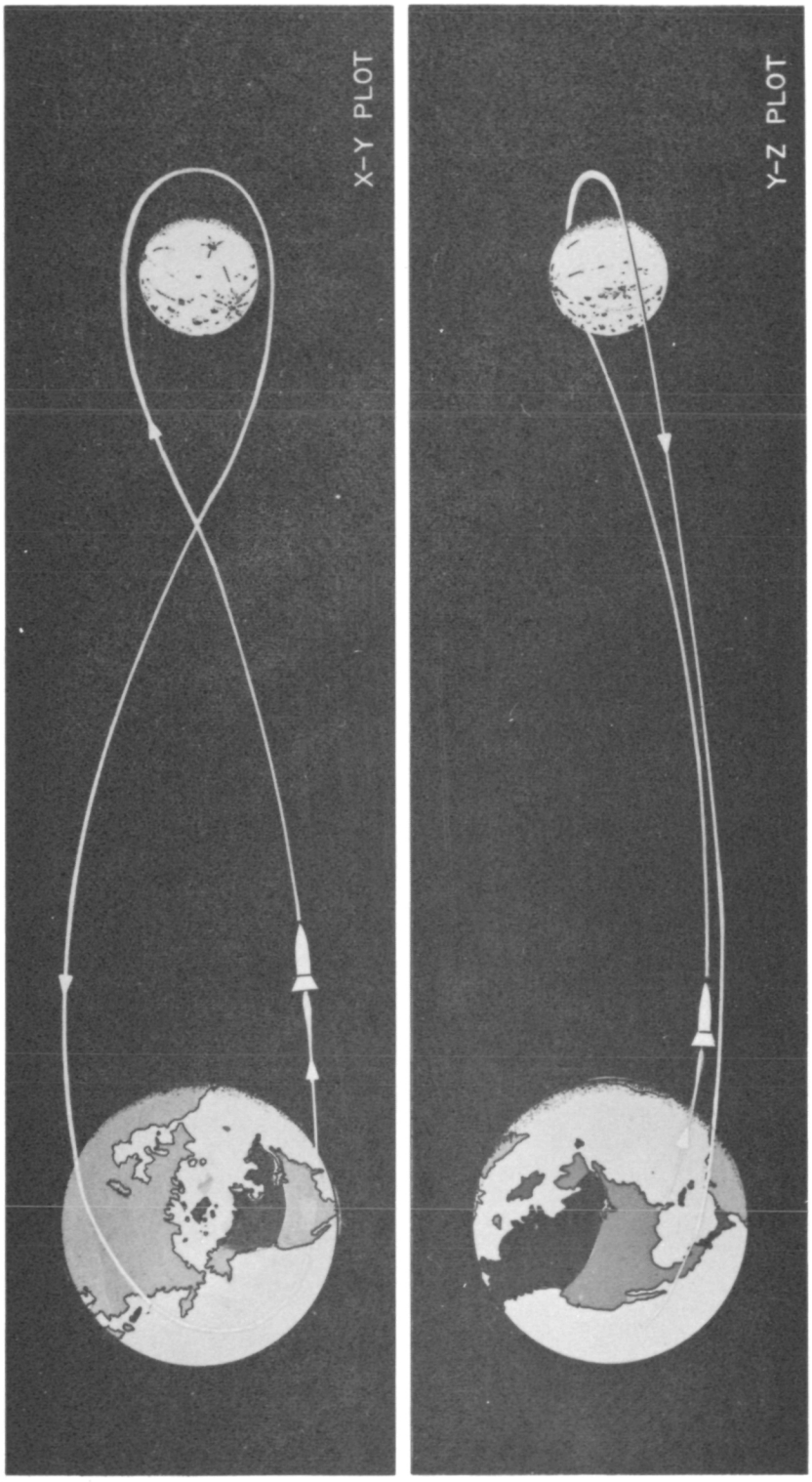

Figure I-10-37. Space trajectory plotting board

1. Aeromedical Displays
2. Environmental Control Displays
3. Systems Displays
4. Trajectory Plotting Displays

1. Aeromedical Displays

Due to the inherent complexity attached to the additional number of astronauts, this display area of necessity must be longer than that currently in use at the Mercury Control Center. Other key environmental data affecting man's performance will also be recorded and displayed. Included are such factors as accumulated radiation, "g" loadings, etc.

As a result of longer flight durations, additional personnel data of interest will also be displayed, such as individual rest and sleep periods and other pertinent human factor data applicable to the longer flight durations.

2. Environmental Displays

This display area contains the same basic data as currently displayed but due to the additional complexity and increased life capability, the displays of necessity are more comprehensive.

3. Systems Displays

Entire major system performance data will be displayed on this series of charts. The major portion of the display will be utilized to monitor the spacecraft's propulsion system. Other basic systems to be monitored are the electrical system, the telemetry system, etc.

4. Trajectory Plotting Displays

In addition to the presently provided launch parameters, sufficient detailed trajectory data will be displayed to analyze the on board maneuvering abilities as flight path corrections are made. Detailed

velocity, distance ground position, abort location prediction and normal landing point predictions are displayed to permit ground computations to be performed on a continuing basis throughout the entire flight regimes.

10.4.3.2 NEW TRACKING STATION

a) Siting

In order to establish the most favorable location for the new tracking station in the Philippine Islands area, a siting team should be sent to this area. Since the new tracking station will be similar to the existing Mercury tracking stations basically the same siting criteria will be applicable. The site selected should conform to the following characteristics.

1) Accessible by vehicle.

2) Maximum unobstructed horizon line of sight compatible with tracking objectives.

3) A reasonably level area large enough to locate the station facilities as defined by minimum spacing criteria.

4) Soils capable of supporting the station structures within the required deflection limitations.

5) Availability of an adequate water supply.

6) No electrical radiation interferences from other installations outside of the station area.

In addition, the availability of logistic services such as communications, utilities, medical services, housing, local labor, supplies and materials, docking facilities, etc., should carry considerable weight in the final selection of the site.

b) Buildings

The number of buildings required at the tracking station should be kept at a minimum. For the station proposed, a Telemetry and Control Building and a Power Generation Building will be required at the main site. In addition, Receiver and Transmitter Buildings will be required at the Long-Range Radio Receiver and Transmitter Areas. A typical tracking site arrangement is shown in Figure I-10-38.

All buildings will be one-story structures with metal frames and corrugated metal roofing and siding. These buildings will be supported on a reinforced concrete slab on grade. As part of the site investigation, consideration should be given to the use of local building materials and methods of construction. If it is evident that these will provide a building that is structurally adequate and more economical than the metal frame buildings, they should be utilized wherever possible.

c) Towers

Several different types of towers have previously been provided at tracking stations. The following towers should be adequate at the proposed new tracking stations

1) Telemetry, Acquisition and Communications Towers—low, structural steel towers supporting steerable antennas, which are located adjacent to the buildings housing associated equipment. This type tower is preferably provided in a prefabricated form for ease of erection.

2) Radar Tower—a reinforced concrete tower supporting a steerable antenna. If building facilities are required for the radar, the tower can be designed as an integral part of the building.

3) Long-Range Radio Receiver and Transmitter Towers—these are usually a series of guyed steel pipe poles set in the shape of a rhombus. However, a steerable log-periodic-type antenna on a steel tower has been used in place of the rhombic type.

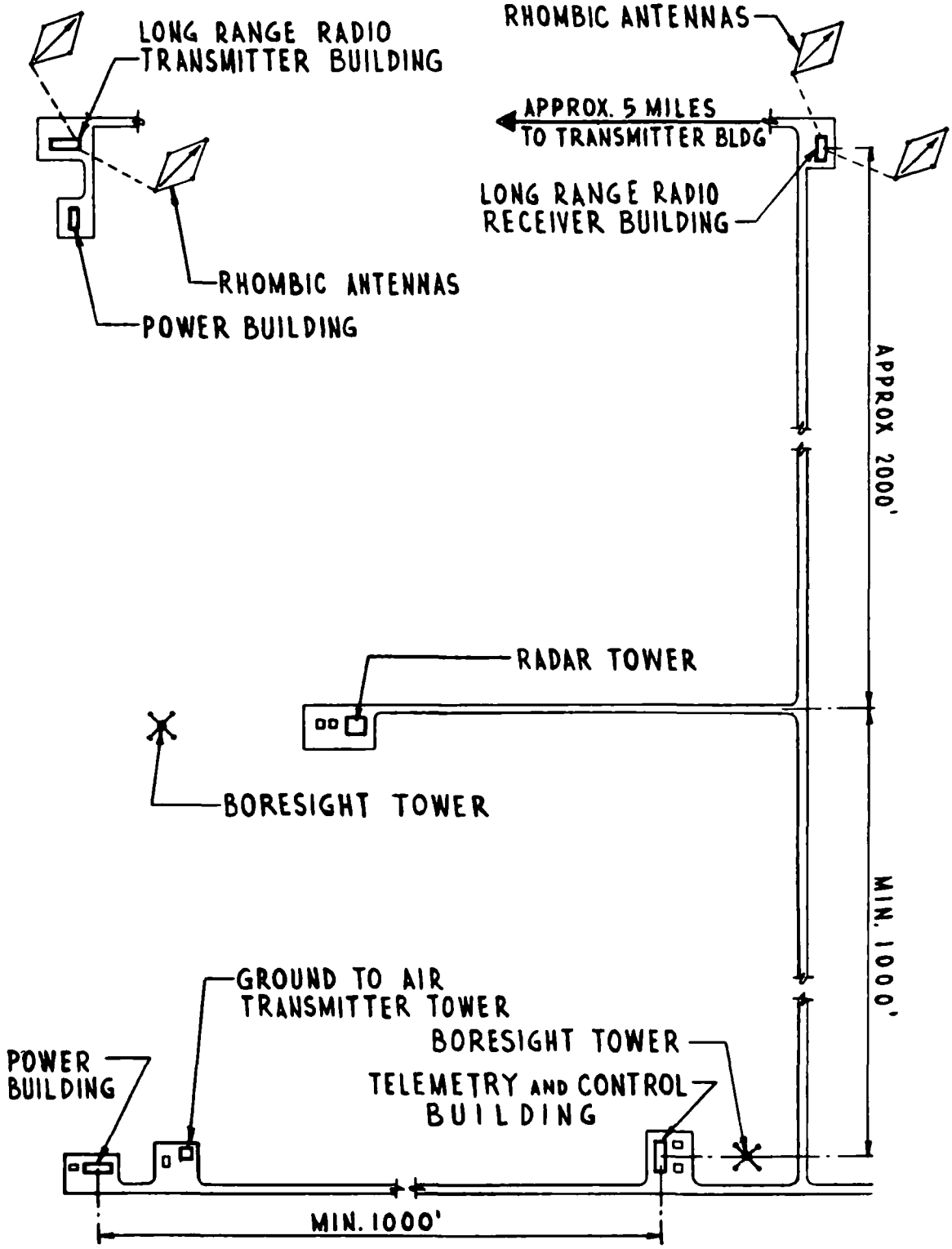

Figure I-10-38. New tracking station - site plan

4) Boresight Towers—steel pipe poles guyed in four directions which may extend to a height of 100 feet.

The foundation design for the above towers will depend on the type of "on-site" soils encountered. Access roads are required to all of the towers with limited parking areas and hardstands for equipment vans if required.

d) Utilities

The new tracking station will require an electrical arrangement similar to that of existing Mercury stations. Diesel engine generator sets will provide power to isolated utility and electronic buses at the main installation and additional diesel generator sets will provide power to a single bus at the Long-Range Radio Transmitter installations. These generators will have kva and voltage ratings compatible with the load requirements they are serving.

Because the specific site location of the new station cannot be firmly fixed at this time, it is not possible to ascertain if commercial power will be available. However, if dependable commercial power is available it can be used to supply power to the utility bus at the main installation, which should reduce the number of diesel engine generator sets required. Diesel generation should be retained to supply power to the electronic bus since sophisticated electronic equipment usually is not able to tolerate the transients present in a commercial utility system. Diesel generation should also be available as a standby source in case of commercial power interruption. The general one-line arrangement is shown in Figure I-10-39.

Air conditioning will be required both for the electronic equipment cooling and comfort conditioning in the Telemetry and Control Building and the Long-Range Radio Receiver Building. The system will be designed to maintain ambient conditions of 75 degrees F dry bulb and 50 percent relative humidity, unless equipment requirements dictate other limitations.

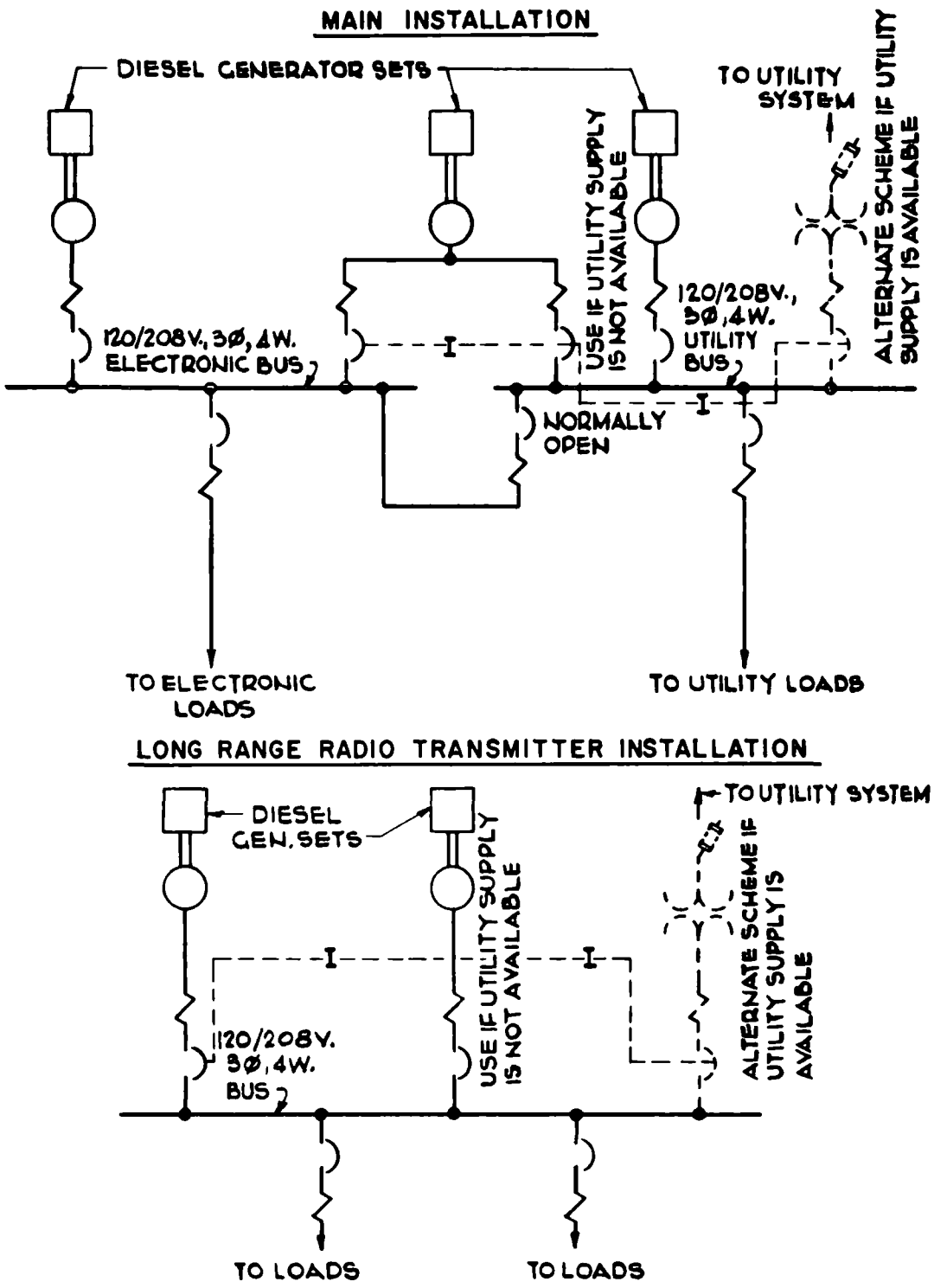

Figure I-10-39. New tracking station - electrical one line diagram

The Telemetry, Communications, Control, Acquisition, Tools and Parts Storage, and general areas of the Telemetry and Control Building will be air conditioned. Packaged air conditioning units of approximately 30-ton capacity each will be required for equipment and comfort cooling. Additional humidity control in the telemetry area can be provided by a humidifier as needed. A fan and ductwork system will distribute the conditioned air in these areas.

Approximately 5 tons of refrigeration will be required for equipment and comfort cooling in the Receiver Building. Humidification should also be provided as needed for humidity control.

Equipment enclosures in the Transmitter Building will be cooled as dictated by the needs of the equipment.

Toilet, sanitary and drinking facilities will be required at the Telemetry and Control Building, the Generator Building, the Radar Tower and the Long-Range Radio Receiver and Transmitter Buildings. A septic tank and tile field should be provided at these sites for sanitary sewage disposal.

If commercial water supply is not available, water from a suitable supply, such as well, rain catchment, etc., and a hydropneumatic tank and pumping facility will be required for the sanitary water and make-up cooling water to all buildings except the Transmitter Building. A separate water supply system will be required for the transmitter area facilities due to the separation distance. Chlorination facilities for water treatment will probably be required for all fresh water systems on the site.

A diesel oil storage facility, oil transfer pump, and operating and monitoring controls will be required at the main installation and at the Long-Range Radio Transmitter installation.

Portable fire fighting equipment will be provided for electrical fires. It is recommended that a pressurized fire main system also be provided for protection against large-magnitude fires.

10.4.4 Recovery Facilities

10.4.4.1 CONTROL BUILDING

a) General

It is planned to use Edwards Air Force Base as one of the locations for landing/recovery control installations. The NASA presently retains an operating installation at this base consisting of hangars and administration facilities. APOLLO system requirements indicate that a Recovery Control Center is the only additional facility required at Edwards AFB. The Control Building will be located adjacent to the existing NASA installation as shown on Figure I-10-40.

b) Construction

It is proposed to provide a facility similar to, but slightly smaller than, APOLLO Control Center at Cape Canaveral. Adequate space will be provided by a one-story, reinforced concrete, frame building with roof of flat slab construction and columns spaced 20 feet on center, except in the control area. This space requires a 60-foot-square area free of columns, as shown on Figure I-10-41, which can be obtained by using reinforced concrete, rigid frame bents. The roof will be reinforced concrete with curtain walls of reinforced concrete block. A removable raised floor, supported by a slab on grade, will be required throughout most of the building for cable and duct runs between equipment. The entire structure will be designed to resist Zone 3 seismic forces, as required by the Pacific Coast Uniform Building Code.

c) Utilities

The electrical power for the recovery facilities at Edwards AFB will be supplied in a pattern similar to that proposed for the Prelaunch Building as shown in Figure I-10-42.

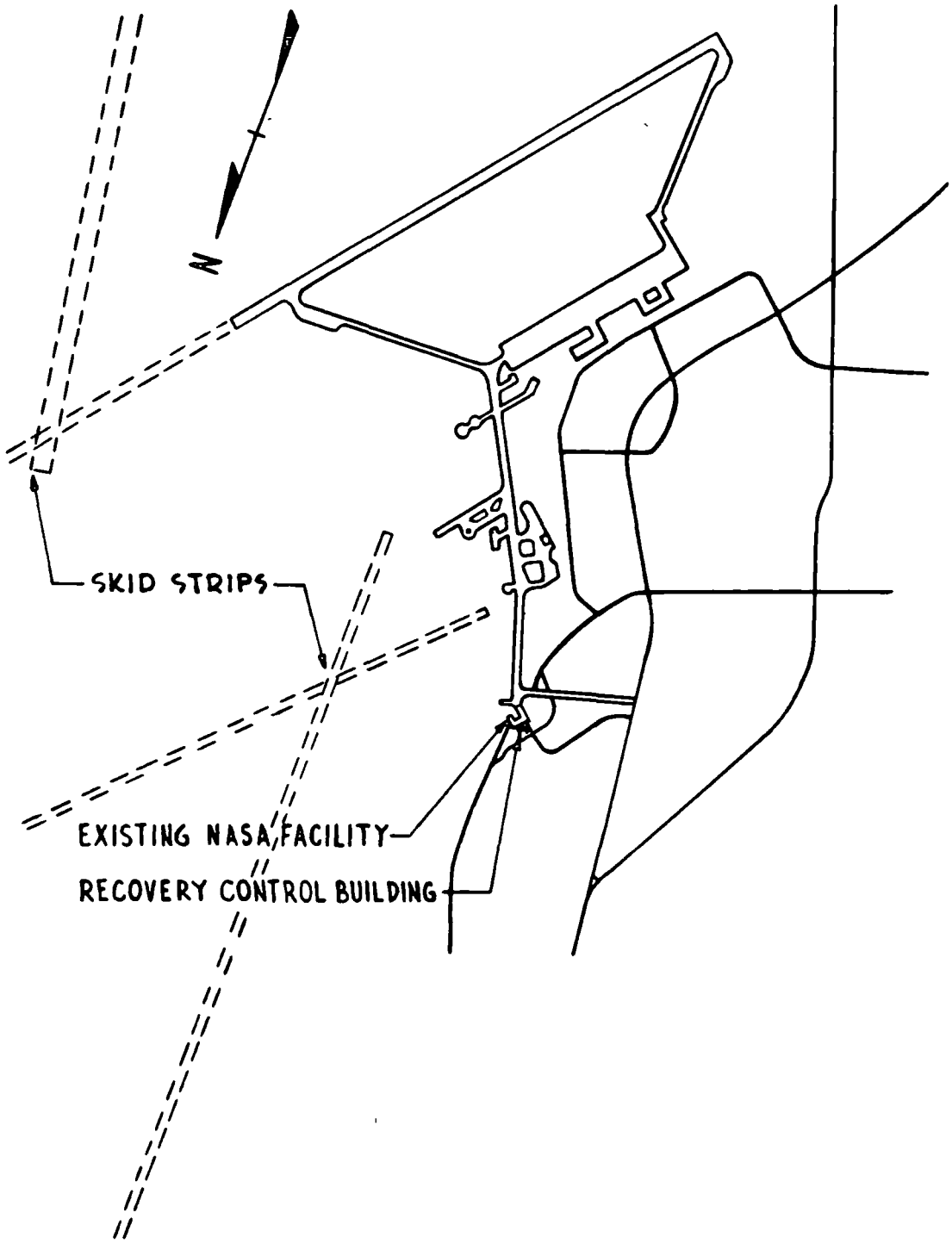

Figure I-10-40. Recovery area - Edwards A.F.B.
Site plan

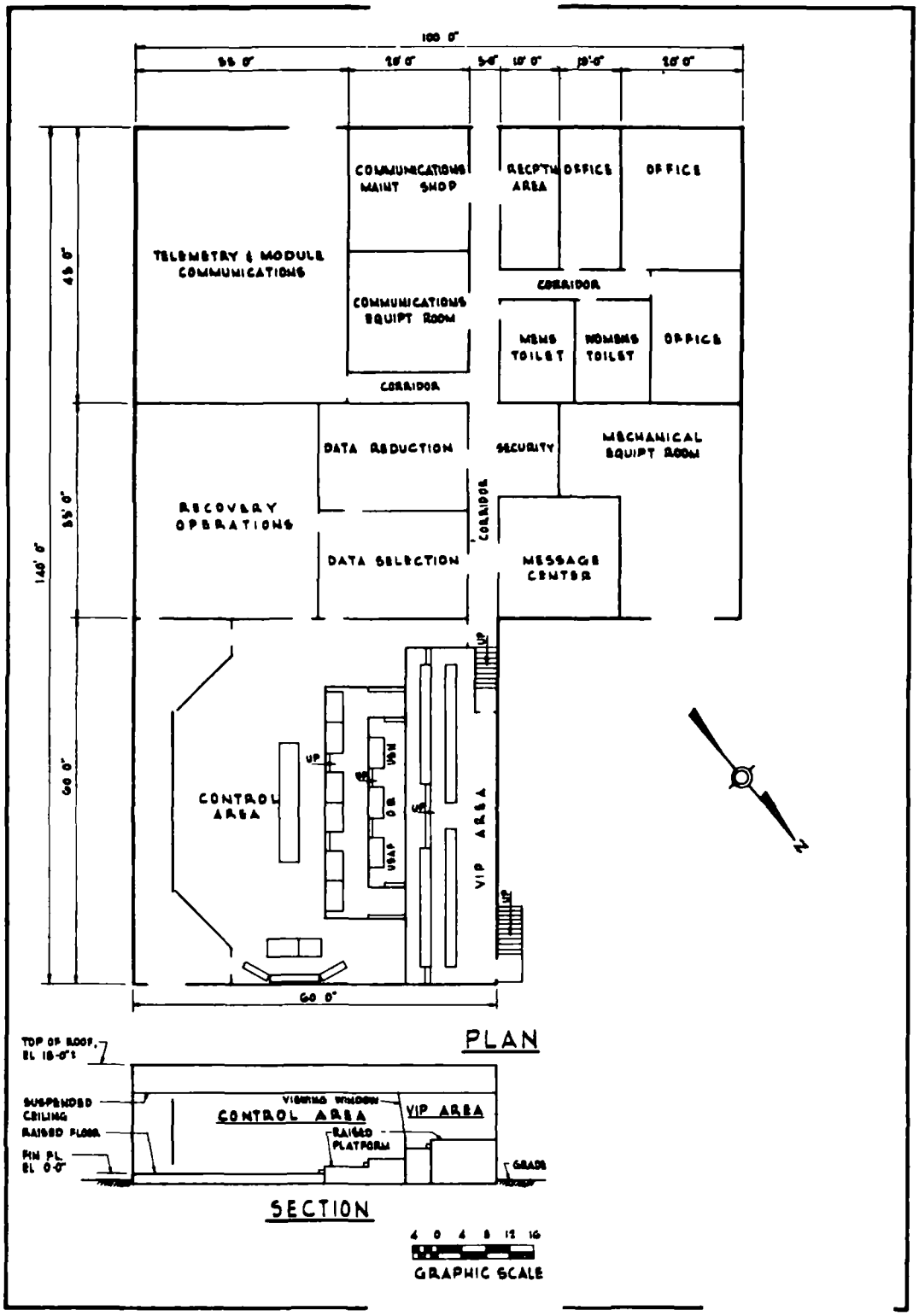

Figure I-10-41. Recovery control building
Plan and section

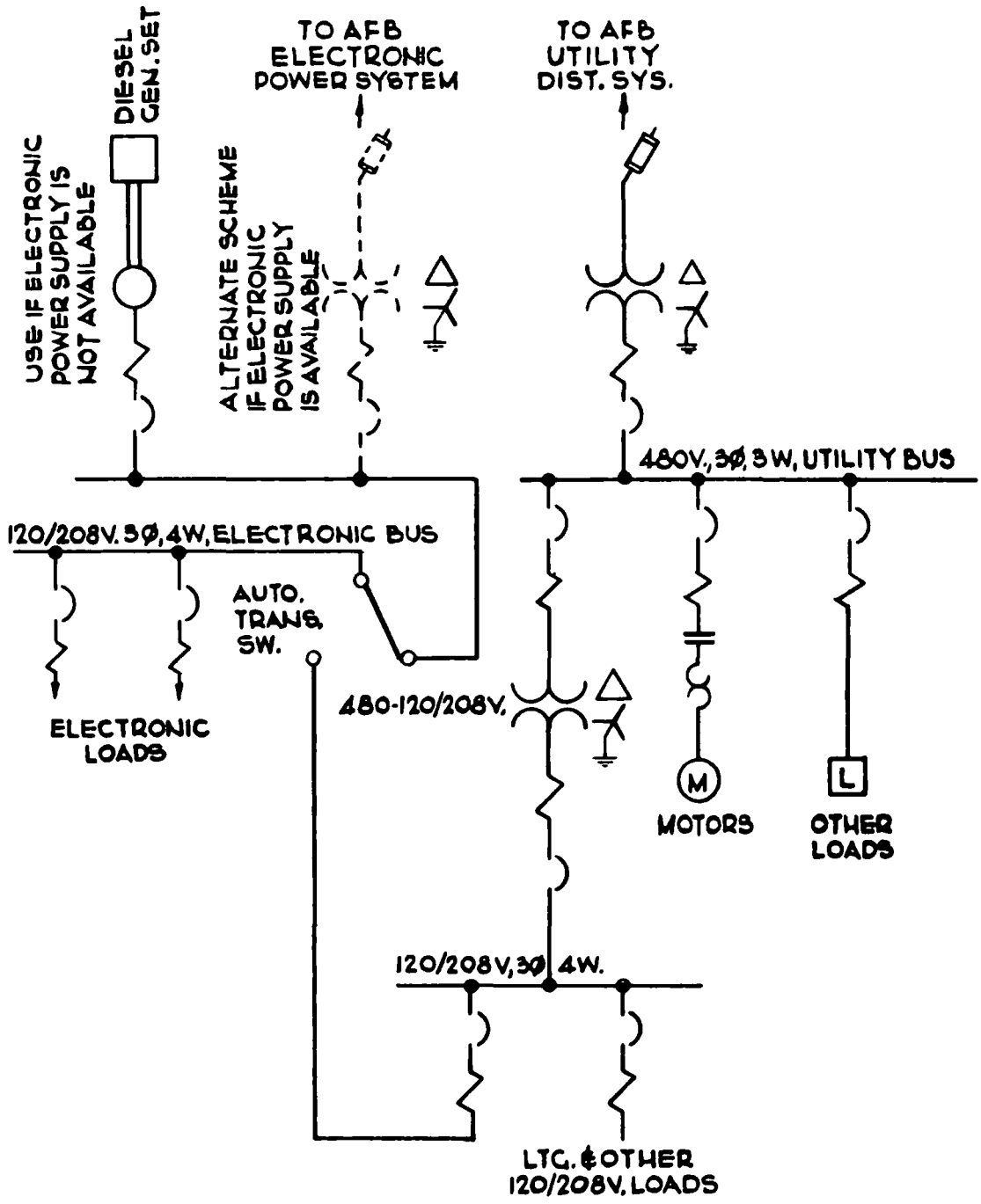

Figure I-10-42. Recovery control building
Electrical one line diagram

Power will be obtained from the base utility distribution system and stepped down through a transformer to 480 volts, 3-phase to supply the 3-phase motors and other loads. A second transformer will provide 120/208 volts, 3-phase, 4-wire for lighting and other single-phase loads.

Since electronic equipment in the Control Center may not be able to tolerate the transients present in the base utility system, electronic power will be obtained from a 120/208-volt, 3-phase, 4-wire bus supplied by a diesel engine generator of sufficient capacity to carry the electronic load. The base utility system will be used as a standby source of power through an automatic transfer switch.

If an electronic power distribution system is available at the Recovery Station, similar to Cape Canaveral, the electronic bus will be connected to this system. In this case diesel power generation will not be required and the base utility system will serve as a standby source of power.

Air conditioning will be required for electronic equipment cooling and comfort. All areas will be air conditioned except the Mechanical Equipment Room and toilets. The system will be designed to maintain the ambient conditions of 75 degrees F dry bulb and 50 percent relative humidity, unless equipment requirements dictate other limitations. The air conditioning system will include a central chilled water unit with air-cooled condensers, air handling units and ductwork for distributing air to all areas and to air-cooled electronic cabinets. Approximately 120 tons of refrigeration will be required. The chilled water unit and air handling units will be located in the Mechanical Equipment Room.

Toilets and Mechanical Equipment Room will be ventilated by exhaust fans.

Sanitary water supply and fire protection systems will be extended from existing installations. Sewage disposal will be by means of septic tank and tile field, or other methods consistent with existing base practices.

10.4.4.2 POSTRECOVERY OPERATIONS AREA

It is proposed to utilize the existing NASA hangar space available at Edwards AFB for all postrecovery operations. These may include such functions as disassembly, testing, analysis of vehicle components, crating and shipping, personnel examination and interrogation. For the proper segregation of these operations it may be necessary to provide partitioning and minor modifications within the hangar area. Since program requirements have not been specifically defined for this phase, it is not possible to indicate detailed modification requirements at this time.

10.4.5 Geodetic Work

10.4.5.1 GENERAL DISCUSSION

With the advent of the Space Age and the many proposed space projects which involve sending manned capsules into earth and extended space orbits the need for precise positioning of world-wide tracking stations has become increasingly important.

Since the tracking information derived from these stations will be used for orbital trajectory calculations, impact prediction, orbital analysis and navigational correction data for manned space vehicles, it is apparent that the reliability of this data for such purposes will be dependent upon the accuracy of station locations as related to a common geodetic datum. A common datum has not yet been universally established and accepted throughout the world.

On Project Mercury it was necessary to establish the radar tracking stations on a new datum, referred to as the "Mercury Datum." Since Mercury tracking stations are to be used for tracking during the various APOLLO flight profiles, it is recommended that all other tracking stations used for Project APOLLO be integrated to the Mercury datum. Tracking of space vehicles can then be accomplished without the probability of trajectory plot position shift during a switch-over between different stations of the tracking range.

10.4.5.2 SURVEY REQUIREMENTS

First-order surveys have been made at all Mercury radar tracking stations. These stations are now located within ± 500 feet with reference to a common geocentric coordinate system. Third-order surveys have been made at the remaining Mercury telemetry stations, but the locating of these stations has not been computed to the Mercury datum. If future program requirements dictate a need to use existing Mercury telemetry stations for tracking purposes, these stations should then be integrated to the Mercury datum. For the purposes of this study, however, it has been assumed that this will not be required.

The DSIF stations at Goldstone, Johannesburg and Woomera have been surveyed to local coordinate, third-order accuracies of approximately ± 1000 feet. There has been no work done on establishing deflection from vertical at these stations, nor have the station locations been computed to the Mercury datum. This work should be accomplished in order to avoid the aforementioned trajectory plot shift during tracking switch-over. Required survey work at these stations should not present too many problems since they are located in close proximity to existing first-order triangulation networks.

Location of existing AMR stations has previously been established to accuracies well within the APOLLO system requirements. Additional survey work will not be required, but station locations will require computational adjustment to the Mercury datum if this has not already been done.

A first-order survey at the new radar tracking station in the Philippine Islands will be required. Existing triangulation networks in the Philippines area are tied to the Tokyo datum and survey results obtained therefrom will require conversion to the Mercury datum. Geodetic surveys for the new station should involve a minimum of field work since extensive geodetic work has already been accomplished in this area.

10.4.5.3 TRACKING SHIP POSITIONING

The proposed use of ocean tracking ships to provide tracking data during orbital missions makes necessary the consideration of position location of these ships to accuracies consistent with the other portions of the tracking range. These vessels will be providing tracking data during launch and orbital phases of the vehicle flights, and also during the critical re-entry and recovery phases. Consequently, tracking information derived from these ships should be of an accuracy sufficient to provide reliability in trajectory position calculations and impact location predictions.

Various systems are in use today for navigation and position determination of vessels at sea. The most commonly known of these are astronomical techniques using marine sextants and star trackers, radio systems such as LORAN and radio direction finders; and inertial navigation systems, which are a more refined and accurate application of the long-standing DRT, or dead reckoning tracer equipment.

The comparative expected accuracies of these systems, together with other, more advanced techniques are indicated in the following tabulation:

TABLE I-10-II

COMPARATIVE ACCURACIES OF USEFUL TECHNIQUES FOR DETERMINING POSITION OF LOCAL REFERENCE AT SEA

Method	Estimated Accuracy	Comments
Artificial Satellites	30 feet	A potential capability requiring considerable development.
Hiran Trilateration	1·30, 000	For long ties of 400-600 miles using instrumental buoys.
Loran B	50 feet	For distances of about 100 miles from baseline.
Loran C	500 feet	For baseline distances of about 1000 miles—not yet fully operational.
Star Tracker	0.5 nautical mile	Dependent on atmospheric conditions.
Marine Sextant	1 nautical mile	Dependent on atmospheric conditions and competence of user.
Inertial Systems	0.5-1.0 nautical mile	Dependent upon accuracy of initial input and continuous drift corrections.

A full appreciation of the limitations of navigation systems presently in use, when applied to missile and satellite tracking functions, can be seen from the following tabulation of estimated station-keeping needs which have previously been projected for PMR requirements.

TABLE I-10-III

Phase	Operation	1960-1965	1965-1975
Launch	Range Safety and I.P. Range	50 ft 5 miles (increases 1 ft/mile)	Same
	Performance Analysis	0.01% of range or 100 feet	0.005% of range or 25 feet
Re-Entry and Recovery	Performance Analysis	250 feet	50 feet
	I.P. and Vectoring	1 mile	1 mile
Orbital	Initial	0.1 nautical mile and 20 feet in altitude	Same
	Precision Trajectory	0.01 nautical mile and 5 feet in altitude	Same
	Nominal Trajectory (Updating orbital parameters)	0.1 nautical mile and 20 feet in altitude	Same

It is apparent that more accurate means of position determination and station keeping at sea must be developed if ships are to be used as a dependable source of tracking data. Many sophisticated and highly accurate types of systems have been proposed in conjunction with other studies. Among these are the following:

a) Underwater Trig Stations, which is a configuration of either passive or active acoustic markers to provide location and depth data.

b) Bathymetric techniques, which indicate position from previously determined topographical characteristics of the ocean bottom.

c) Hiran Trilateration Buoy Position, which utilizes the Hiran system for accurately determining position of a previously set system of buoys.

It is not the intent of this study to elaborate on or pursue the feasibility of any one of these techniques, but only to point out the possibilities for further development in this area. Much study has already been done on these various systems and their application to tracking problems by many organizations well versed in the field of geodesy and related applications. A full and complete evaluation of this particular problem should be included under any future APOLLO geodetic study.

10.5 LOGISTIC SUPPORT PLAN

10.5.1 Introduction

10.5.1.1 PURPOSE

The Missile and Space Vehicle Department (MSVD) of the General Electric Company will provide functional support to the field test operations during the APOLLO Program. During the field systems test and flight test programs; the systems flight and test modules, and aerospace ground equipment will require normal operational support as evidenced in the provisioning of those facilities, services, materials and information necessary for operational capability. In the event of system and module malfunction or failure during test, component or subsystem replacement will be a requirement. In addition, as inherent within an experimental program, design changes will warrant the modification of the hardware at the test sites. Therefore, to support such functioning, MSVD has established a logistic activity which will plan for and provide the resolution of these normal operational activities and the other logistical support requirements.

10.5.1.2 SCOPE

The logistic support plan outlined herein defines the planning necessary to establish the essentials of logistic support required during field systems test and flight test phases of the APOLLO Program.

10.5.1.3 SUMMARY

The Missile and Space Vehicle Department of the General Electric Company will furnish logistical support for the testing of the systems, flight and test modules, and subsystems. Operational plans will be prepared to present the extent of logistic activity required to adequately perform the support functions. The logistic activity will encompass such areas as:

Complete systems knowledge,
Support plans and schedules,
Material provisioning planning,
Documentation control and data reporting,
Hardware modification planning,
Material control and accountability,
Statistical provisioning, and
Organizational liaison function.

10.5.2 Responsibilities

10.5.2.1 GENERAL

The logistic activity of MSVD is responsible for establishing and managing a logistic support program which satisfies the requirements of the field test and flight test programs. In order to accomplish this prime responsibility, the logistic activity will complete certain work functions which include:

Provide and maintain the logistic support plans and schedules required to support the APOLLO Program at the field sites,

Assist in determining and providing the necessary facilities, equipment, and miscellaneous items used in the field,

Determine, provision, and schedule the necessary spare parts to support the test activities in the field,

Plan, prepare, and schedule the modification kits to incorporate hardware changes as issued from Design Engineering,

Maintain configuration control on all systems, flight and test modules, AGE, test equipment, and spare parts at the field sites,

Monitor the return and intersite transfer of materials and hardware to maintain accountability records,

Analyze component behavioral data to recognize any trend in the reliability of the components,

Prepare shipping instructions for all systems, modules, AGE, test equipment, spares and modification kits, and other materials shipped to the field sites,

Maintain accountability of all equipment and materials at the field sites and in possession of the logistic activity at MSVD, Philadelphia,

Terminate or divert all property and materials at the field sites upon completion or termination of the APOLLO Program.

10.5.3 Logistic Planning and Integration

10.5.3.1 GENERAL

The logistic activity of MSVD will provide the management effort required to establish, maintain and satisfy the over-all logistic program goals. In addition, logistic operating procedures will be written and issued to coordinate the activities and work responsibilities with other individual operations.

10.5.3.2 PLANNING

The support of the field test programs requires the provisioning of facilities, services, tools, spares, and other essential items. The first requirement toward providing this support is the acquisition of a complete knowledge and understanding of all the systems, modules and other hardware, the test programs and schedules involved in the program. The test program and system specifications are sources of information used to determine logistic requirements and the test schedules are used to establish the need dates. The detailed logistic plans and schedules are prepared from this collection of preliminary information and, as new pertinent information is received, changes are incorporated in the plans and schedules to reflect these changes.

10.5.3.3 INTEGRATION

Each of the affected operations will be made aware of the logistic plans and support schedules and their revisions as they come into being. In this manner, any points of contention created by or contained in the plans, schedules or revisions may receive prompt rectifying action. All foreseeable interface problems encountered in the implementation of the logistic support plan will be resolved during the writing of the operating procedures.

10.5.4 Facilities Provisioning

10.5.4.1 GENERAL

The proper execution of the logistic support plan requires MSVD to provide facilities for the testing, storage, maintenance, and modification of the systems, modules, and AGE. Initially a study will be made of the APOLLO Program requirements by MSVD. The result of the study will be facility designs and support requirements. The designs and requirements will be used to prepare specifications which will utilize existing facilities in present or modified form where these are available and for new facilities where none presently exist. The Philadelphia facility will then procure the field facilities required for the APOLLO Program.

10.5.4.2 DATA CONSIDERATIONS

The facilities which are normally required by the logistic activities involve areas for the storage and issue of parts, equipment and materials, for procurement and shipments of same, and for administration and records keeping. The following factors will be evaluated on the basis of program requirements:

Space
Power
Lighting
Security and fire protection
Communications
Transportation
Special considerations

10.5.5 Spare Parts Control

10.5.5.1 PROVISIONING

The preparation of the spares and spare parts lists occur concurrently with the development of the systems and modules. As soon as firm design decisions are made, documents such as the following become basic sources of information for use in preparing the preliminary list of spares:

System and module drawing tree,
System and module connections diagram,
System and module assembly and sub-assembly breakdown,
Subsystem breakdown,
AGE mechanical equipment, and
AGE electrical equipment.

Lists of all the components used in the systems and modules are prepared from these documents as possible spares and result in:

System and module components list,
System and module parts and hardware list,
AGE mechanical components list, and
AGE electrical components list.

These lists are then studied to select components on the basis of reliability. In addition, recommendations are made by design engineers, component engineers, and field instrumentation and systems engineers as to the types and levels of spares to be stacked. Also, behavioral information as evidenced in failure and consumption reports from in-house testing labs, and on similar and identical components used in previous MSVD programs is factored into the compilation. Tentative lists of spares are then prepared from this collection of information as:

System and module spares list, and
AGE spares list.

The tentative spares lists are then used as working guides to evaluate the following factors for each spare:

Firmness of design,
Quantity per system, module or AGE set,
Quantity of systems, modules, and AGE sets,
Item cost,
Budget allowances,
Ordering lead time,
Replaceability in field,
Replaceability time in field,
Interchangeability,
Average repair time,
Operating life,
In-flight operating time, and
Shelf life.

After the initial provisioning lists have been prepared, a study will be made of the systems, modules, and AGE delivery schedules. This study will result in the preparation of a spares delivery schedule which will have the spares delivered to the test sites two weeks or more before delivery of the prime hardware. The early delivery date assures the availability of the spares when the hardware arrives and allows use of economical modes of transportation. A spares procurement schedule will then be issued for accumulation of the listed spares. All items on the initial spares lists on which the lead time indicates a period of unavailability beyond delivery of initial prime hardware (calculated from planned ordering date) will be pilot ordered on an estimated basis. Adjustments will be made as required to pilot orders upon the establishment of firm listings. A spares up-dating program will be maintained on a continuing basis to incorporate changes in program schedules, component reliability, and hardware design. The spares provisioning lists will be revised periodically according to the reliability trend indications brought out by statistical analysis. The statistical analysis will be performed on the results of tests conducted during vendor and in-house processing. Inputs for reliability determinations are obtained from sources such as:

Accelerated life tests,
Electrical characteristic tests,
Vendor acceptance and qualification tests,
MSVD acceptance and qualification tests,
Component tests,
Systems tests, and
Field tests.

10.5.5.2 STOCK, STORAGE AND ISSUE

Stock status at the field sites will be controlled through the MSVD Stock Status System. The system is designed for the automatic replenishment of spares through the use of the mechanized (electronic data processing) stock status system. This

system enables the maintenance of minimal stock levels which substantially reduce warehousing area and enables maximum delivery time.

The spares will be accumulated in Philadelphia and shipped to the field according to the spares delivery schedule. Existing assets from other programs will be utilized where practical to reduce program costs. Upon the availability of suitable field storage area, spares will be stored in the field in an inspected and packaged condition. Classified items will be stacked in secured areas according to security regulations. Special requirements for shipping and storage will be monitored by MSVD to assure compliance to established specifications. The normal operating procedures of the logistic activity will be sufficiently flexible to accommodate emergency item requests from the field. Emergency spares will be made available to the field on an "as requested" basis.

10.5.6 Field Hardware Modification

10.5.6.1 GENERAL

Each engineering operation is responsible for coordinating all design changes to components, subsystems, systems, modules and AGE, and all changes to specifications, test requirements, and the like which may require modification of the field hardware. The modification to the hardware will normally be performed "in situ", however, the hardware may be returned to MSVD, Philadelphia, for modification when expedient.

The location for the accomplishment of the modification will be determined by the Program Office after review of all pertinent information and consultation with all other affected operations. If it is determined to have the hardware returned to Philadelphia, the logistics activity will issue shipping instructions to the field location for the return.

10.5.6.2 MODIFICATIONS

As soon as enough information concerning a pending modification is accumulated which will define the task, the task is integrated into the logistic support schedule. A list of required material is drawn up and orders are placed to provide material sufficient to complete the modification. Instructions as to the extent of modification activity required and a list of reference documents pertaining to the change are prepared. When the modification materials are received, they are assembled into a kit along with the instructions and supporting documentation. These kits, known as retrofit kits, consist of a complete package of all materials, tools of special design, instructions on the accomplishment of the change, and supporting documentation. The documentation includes:

Reason for modification,
List of applicable drawings or specifications,
List of applicable Alteration Notices (AN) and Unit Change Instructions (UCI),
Specific information on effectivity and classification code,
List of materials,
Installing instructions,
Disposition of removed materials, and
Special test instructions and procedures.

The modification will be installed by the field personnel using the retrofit kit and the Philadelphia facility will be notified of the completion.

Upon the occasion that the field site will require emergency modification of the hardware during a test program, the planning will be issued by the field personnel after obtaining approval of the responsible engineering operations at the Philadelphia facility. A liaison function, maintained by the logistics activity, will promote the exchange of information between the field sites and Philadelphia relating to field changes and emergency item requests.

To assure maximum compatibility between in-house and field site test equipment, Philadelphia engineering operations will authorize all test equipment modifications. Identical in-house and field site test methods are a prerequisite to reliable test results. Test equipment modifications generated at the field site will be incorporated into the in-house test equipment. The actual incorporation will be controlled by the responsible engineering group on the in-house equipment.

10.5.6.3 CONFIGURATION CONTROL

Configuration control will be performed by MSVD through record maintenance on all systems, modules, subsystems and AGE sets shipped to the field sites. These records will include such information as:

Nomenclature,
Drawing number,
Serial number and set assignment,
Location at field site,
Applicable modifications,
Modifications completed, and
Modification numbers and file numbers of modifications issued.

A technical systems knowledge will be maintained by MSVD to facilitate configuration control through a continuing review of design information, specifications, test instructions, and design change information.

10.5.7 Material Control and Accountability

10.5.7.1 MATERIAL CONTROL

During the APOLLO Program, MSVD will maintain property control of all MSVD and government equipment and materials located at the field sites and housed at the Philadelphia facility. MSVD will direct and coordinate the transfer of this property between different field sites and between the Philadelphia facility and the field sites.

10.5.7.2 MATERIAL ACCOUNTABILITY

Accountability records will be maintained on all MSVD and government property located at the field sites and housed at the Philadelphia facility. All property will be recorded and identified immediately upon receipt and this property will remain so identified as long as it is in the custody, control or possession of the MSVD operations. Shipping documents will be entered into the inventory accounting system where the property will be held accountable against the operation until expended, scrapped, terminated, or transfer of accountability to another operation is authorized. At the termination of or the completion of the APOLLO Program the status of all MSVD and government property will be determined. At this time a physical inventory will be made of all property, the records of all property shipped or disposed of will be reviewed according to instructions from the MSVD and government property administrator to ascertain that all property has been accounted for and the interest of both parties protected in this respect. The inventoried property will be disposed of or diverted according to instructions from the responsible property administrator.

10.5.8 Documentation Control and Data Reporting

10.5.8.1 GENERAL

The foundation of the logistic support system is based on the exchange of information. Information is required for effective management control of the logistic program, for use in the provisioning of spares, for the planning of the total logistic program, and for countless other logistical work elements. In turn, logistic data and documents are generated for dissemination to other organizations and MSVD operations on logistical matters. Procedures will be established to govern the preparation, processing, transmission, and storage of data and documents under an integrated system reporting technique. The same system will provide for the control of the reported data.

In many cases, the data transmitted will contain classified material. These reports will be handled in accordance with the regulations governing the handling of classified documents.

11.0 Training and Indoctrination Plans

For the APOLLO manned space flight operations a systematic training program will be implemented in those areas that will contribute to the proficiency of the human operator and reliability in his performance. This is of fundamental importance since human operator error in any phase could compromise safety of the crew and success of the mission. Thus, for the Training and Indoctrination Program, the complete personnel support complex will be considered. The broad categories of personnel who perform in the total APOLLO system may be designated as follows:

(1) Space vehicle crew

(2) Flight-supporting ground, landing and recovery crews

(3) Ground support crews; in-flight preparation, checkout, servicing, installation, manufacture and assembly, and launch activities

(4) Scientific monitoring and advisory personnel

The experience gained from other man-in-space programs, such as Mercury, Dyna-Soar, and the X-15, will be consolidated and prepared as a basic course in indoctrination for both the flight and ground crews. Figure I-11-1 is the planned schedule of training and indoctrination for all categories of personnel. Table I-11-I presents in detail the modes of training and Table I-11-II the listing of equipment to be used.

11.1 FLIGHT CREWS

A thorough course of study in the theory, orientation, operation, and in-flight maintenance and repair of the APOLLO space vehicle and its systems will be conducted for the flight crews. Much use will be made of cabin displays and mock-ups of the various systems.

In addition, the flight crews will participate whenever feasible in the test program. Participation in qualification and flight certification tests will be encouraged. Participation in such tests as flotation or set-out tests of the command module will be mandatory. Here will be learned the important areas of water and land survival, emergency egress and operation of search and recovery aids under the actual operating conditions. Another example of a demonstration test which will be used for training purposes is structure and ablation shield repairs. The practice gained in making such repairs, as well as the demonstration of the integrity of the repair, will be invaluable.

Indoctrination in and acclimatization to the various environments encountered in space flight will be a part of the training program. Experiencing acceleration while performing tasks in a simulator mounted on a centrifuge will help the astronauts to better learn ways of operating during launch, midcourse correction and re-entry accelerations. Vibration and acoustic noise environments will also be applied to the simulator for the same reasons. Keplerian trajectory flights and water tanks will be employed for indoctrination in performance during the weightless phenomenon.

A stringent physical fitness program consisting principally of gymnastics and calisthenics will be carried on throughout the program. In addition, sports such as golf, baseball, swimming and basketball will be utilized, but to a lesser degree.

A most important phase of the training program is the use of mission simulators. These simulators will be used for flight and ground crew indoctrination, compatibility training and conducting of complete simulated missions. By programming errors or situations into the simulator, training in methods and procedures under all conceivable conditions will be accomplished.

The simulators will realistically and faithfully reproduce all elements of the missions which state-of-the-art permits.

11.2 GROUND CREWS

One of the most important areas of indoctrination for the ground handling crews and launch crews will be that of equipment familiarization. For purposes of making all the comprehensive ground tests, checkouts and inspections, it is essential they be given a comprehensive course in the theory and operation of the APOLLO space vehicle equipment.

The communication crews will participate in the mission simulation exercises performed by the flight crews in the mission simulators.

The tracking station crews will derive most of their training from the unmanned orbit flights prior to the manned flights. However, use will be made of satellite and other appropriate programs where feasible.

The ground control stations crews will participate in the simulated mission exercises as well as receive theory courses in the APOLLO systems. Methods of data reduction and readout will be presented to improve their ability to make decisions based on judgment of the situations which can be programmed into the mission simulators.

The landing and recovery crews will be trained in recovery operations and methods for both normal and abort missions. Much use will be made of the experience gained by units of the U.S. Navy fleet operations such as are accomplished at Atlantic Missile Range on Mercury and at the Pacific Missile Range on numerous programs. The set-out tests and drop-tests will also provide valuable training for these crews.

11.3 SCIENTIFIC AND ADVISORY PERSONNEL

The areas in which scientific and advisory personnel will require specialization will include various medical specialties, and those areas most pertinent to the vehicle system and mission. APOLLO system and design engineers will be on

hand as equipment experts, who, in addition to having the basic knowledge in the design and operation of the system on a project basis, will have undergone indoctrination on crew problems. Other advisory personnel would include astrophysicists, geologists and geophysicists specializing in lunar topography, radio biologists, geneticists, all of whom will have undergone indoctrination on the APOLLO system and mission objectives.

Medical specialists will directly participate in the selection and training of the flight crews. Rigid monitoring of the physical fitness program and general physical status of the astronauts will be required.

Medical specialists will work as a team at the tracking stations with engineers who will check APOLLO compartment environments, while the medical monitoring will include such things as heart action, respiration and body temperature. In addition, physicians will be assigned to various recovery teams to administer medical treatment to returning astronauts as required.

Engineering personnel must, of course, keep abreast of the state-of-the-art throughout APOLLO project developments. Special symposia and instruction will be required to familiarize them with particular crew and environment problems.

Current state-of-the-art, and integration of space-probe and space-flight experience on such parameters as radiation, meteoritic hazards and solar storms, must be maintained by assigned astrophysicists. This will be accomplished by such means as lecture, symposia, and dissemination of data in report form. Current lunar data will also be disseminated in similar fashion.

Space surgeon training will at least consist of a general background provided in the tri-service pool of medical specialists that is currently developing at Cape Canaveral under the Air Force Medical Training Center Command.

Medical personnel assigned to monitoring functions on the Command-Center tracking team will undergo detailed training on the APOLLO system, including medical records and histories of each individual APOLLO astronaut. On the other hand, for those assigned to recovery teams, only informal familiarization with the APOLLO project may be necessary.

11.4 SUMMARY

The importance of a well planned and coordinated Training and Indoctrination Program cannot be over-emphasized. All personnel involved, knowing what to do and when to do it, can be the difference between success or failure. Their having the ability to make rapid, well informed decisions based on the experience of hours of training can mean the difference between man land-locked or man reaching the moon. The training and indoctrination schedule is integrated into the Integrated Program Plan presented in Section 2.0 and is shown in Figure I-11-1.

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TABLE I-11-I. APOLLO VEHICLE CREW TRAINING PROGRAM

Training Requirement	Hours	Training Methods	Training Devices	Means of Obtaining Criteria of Proficiency
1. Knowledge and Concepts		Lecture-Demonstration Automated Instruction	Slides Motion Pictures	Paper-and-pencil tests Teaching machine records
A. Space Fundamentals, e.g. Celestial Mechanics Space Navigation Propulsion Human Physiology First Aid Survival Geography Electronics	350	Individual Study	Mock-Ups Teaching Machines Texts	
B. APOLLO Subsystems (theory and method of operation, detection and correction of malfunctions) Life Support Electric Power Communications Flight Path Management Propulsion Scientific Observation	400	Lecture-Demonstration Individual Study Automated Instruction Discussion	Visual Aids Mock-Ups Teaching Machines Manuals Operational Equipment Part-task trainers	Paper-and-pencil tests Teaching machine records Job-sample tests
2. Adaptation and Physical Conditioning				
A. Physical Training	350	Individual Exercises Competitive Sports	Gym Equipment Sports Equipment	Physical Fitness tests
B. Adaptation to Stresses of Space Environment, e.g. Acceleration Weightlessness Tumbling Heat	250	Exposure to stresses	Open loop centrifuge Tumbling Devices Vibration Devices Water Tank KC-130 & KC-135 Zero-G flights Mercury & Dynasoar flights	Physiological Measures

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TABLE I-11-I (Continued)

Training Equipment	Hours	Training Methods	Training Devices	Means of Obtaining Criteria of Proficiency
3. Individual Skills				
A. Mission Phase Procedures for Pre-launch Launch Boost Midcourse Outbound Lunar Orbit, Reconnaissance, and Initiation of Earth-bound trajectory Midcourse Inbound Re-entry Landing Survival	500	Lecture-Demonstration Individual Study Automated Instruction Controlled Practice	Visual Aids Manuals Teaching Machines Part-task Trainers Mission Module Simulator Re-entry Module Simulator Navigator Station Simulator-centrifuge combination	Paper-and-pencil tests Teaching Machine Records Job Sample Tests
B. In-Flight Maintenance	250	Lecture-Demonstration Controlled Practice Automated Instruction	Visual Aids Mock-Ups Operational Equipment Teaching Machines Link MAINTRAINER Simulators (programmed malfunctions)	Paper-and-pencil tests Teaching Machine Records Job-Sample Tests
4. Crew Coordination Skills				
A. Integrating Mission Phases	150	Controlled Practices	Mission Module Sim Re-entry Module Sim. Navigation Station Sim.	Job-Sample Tests
B. Coordination among Crew Members	150	Controlled Practice	Mission Module Sim. Re-entry Module Sim	Job-Sample Tests
5. Refresher, Retention, and Keep Current Training	600	All of above, as appropriate	All of above, as appropriate	All of above, as appropriate
TOTAL HOURS (18 month program)	3000			

1. Simulators

   A. Mission Module Simulator — May be used separately or together: When used together, they constitute the Mission Simulator

   B. Re-entry Module Simulator

   C. Vehicle Commander's Station Simulator (to be usable, closed loop, on human centrifuge)

2. Adaptation Devices

   A. Open Loop Human Centrifuge

   B. KC-130 and KC-135 (for zero G Keplerian trajectory flights)

   C. Water Tanks (for zero G simulation)

   D. Air Bearing Platform

   E. Tumbling-Disorientation Device

   F. Vibration-Buffeting Device

   G. Confinement-Life Support Equipment Trainer

3. Part-Task and Procedures Trainers - including

   Antenna Steering Training

   Solar Collector Orientation Trainer

   Vehicle Egress and Survival Trainer (land) — Command Modules from Set Out Tests

   Vehicle Egress and Survival Trainer (water)

   Star Tracker Trainer

   Emergency Procedures Trainer(s)

   In-Flight Maintenance Trainer(s)

   Scientific Observations Trainer

4. Visual Aids and Mock-Ups

5. Teaching Machines

TABLE I-11-II. APOLLO VEHICLE CREW TRAINING EQUIPMENTS

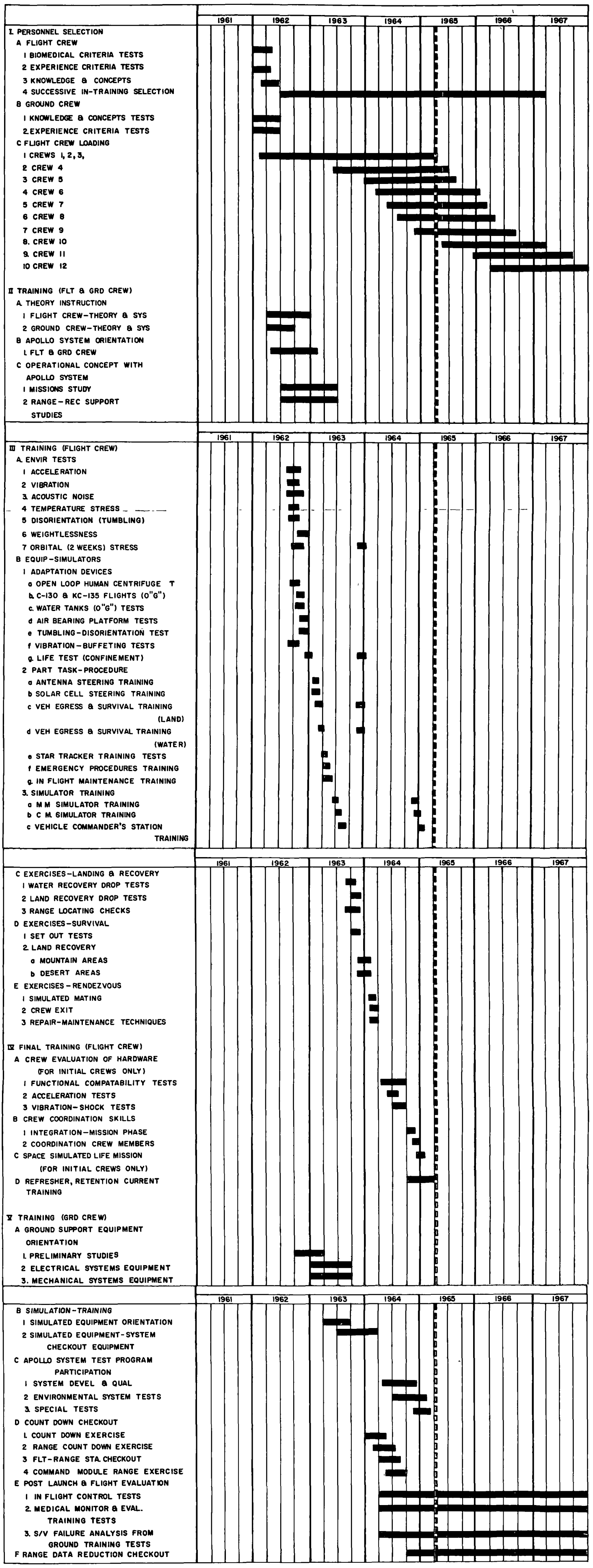


Figure I-11-1. Trauning and indoctrination schedule

APPENDICES

A Apollo Parts Program

A program of assuring that all components receive the most thorough and meticulous attention in design shall be made by patterning this engineering effort closely along the lines undertaken,and in effect,on the Advent Program.

As presented at the meeting on the APOLLO Reliability Program, held in Philadelphia May 2, 1961, and attended by the following NASA Headquarters personnel (J. C. French, H. Patterson, J. T. Koppenhaver, and Catherine D. Hock), this involves a specific program of attention to each parts and materials item and to the application data by which these are incorporated into the components and subsystems of the APOLLO system.

CHART #1

APOLLO COMPONENT CONTROL

1. PARTS
2. MATERIALS
3. APPLICATION DATA

In this respect, although the Advent system is one designed for long life (i.e. one year to three years) and involves an unmanned space vehicle, it is felt that the same design methods and techniques must be applied for short life (i.e. two weeks) of a manned space vehicle, and that every known applicable engineering method must be applied to assure that the availability of personnel in the space vehicle is considered as providing a maintenance capability which is used to enhance the reliability of the best and most reliable equipment which can be built within the limitations of the program (i.e. time, funding, etc.) and the state of the engineering art involved.

CHART #II

LONG LIFE (1 YEAR ++)
UNMANNED
SPACE VEHICLE
DESIGN METHODS

APPLIED TO

SHORT LIFE (2 WEEKS)
MANNED
SPACE VEHICLE
DESIGN REQUIREMENTS

Thus, failure free life is the sole objective of the engineering effort which may be applied to the APOLLO Program. The complexity of the system, the dependence of mission success upon the successful performance of the parts and materials involved in each of the portions of the mission and the unmeasurable importance of the lives of the crew members involved, as well as the importance of the success of this program to the nation, requires that attention be given to each detail of the system. And, that full benefit be taken of all existing programs (e.g. the Minuteman parts development programs, experience and data which may become available from the Mercury Program, data from the Advent Program, etc.) in the design and development and verification of the reliability which is designed into the APOLLO space vehicle and each of its subsystems.

CHART #III

FAILURE - FREE LIFE
IS SOLE OBJECTIVE
EVEN THOUGH THE
MANNED SPACE VEHICLE
HAS A MAINTENANCE
CAPABILITY

1. COMPLEXITY
2. DEPENDENCE UPON PARTS
3. UNMEASURABLE IMPORTANCE OF "LIFE" OF THE CREW MEMBERS

The following brief, covering the presentation made on May 2, 1961, of the Advent Reliability Program, is to be considered illustrative and indicative of the program proposed for the APOLLO Project.

Chart IV indicates the major portion of the parts program, with an indication that the purchase specifications and the quality assurance provisions documents, recently completed under Item 5, represents the quality of parts obtainable from "Minuteman" parts manufacturers. This level of quality, together with such additional screening and control procedures as these and other manufacturers have proposed for incorporation into the Advent parts program, is the quality level to be incorporated in each APOLLO piece part and assembly. 100 percent screening and control during manufacture and 100 percent component tests under complete space environment, as well as extended acceptance tests in vacuum (as well as in other applicable environments), is proposed as essential to the APOLLO Program.

CHART #IV

PARTS PROGRAM

1. GENERAL BACKGROUND
2. SELECTION
3. QUALITY ASSURANCE
4. MANUFACTURER VISITS
5. PURCHASE SPECIFICATION & QUALITY ASSURANCE PROVISIONS
6. SCREENING & CONTROL – MANUFACTURE
7. COMPONENT TEST – & ORBIT

Chart V and Chart VI cover the objectives and criteria applicable to the attainment of failure free life during these missions.

Chart VII is to clarify certain terms used in connection with testing programs specifically designed and verified as significantly improving the reliability of each part assembled into production hardware.

CHART #V

ADVENT PARTS – OBJECTIVES & CRITERIA

I. OBJECTIVE: **FAILURE FREE LIFE**

TO THIS OBJECTIVE **ALL OTHERS ARE SUBORDINATED** INCLUDING: COST, DELIVERY, MULTIPLE SOURCE, ETC.

WITHIN THIS OBJECTIVE **PERFORMANCE** AND **WEIGHT** ARE OVERRIDING REQUIREMENTS **ONLY** BY PROGRAM OFFICE DECISIONS UPON SPECIFIC ALTERNATIVES

II. CRITERIA:

1. MINIMUM NUMBER OF TYPES & MATERIALS
   (a) WITH EACH ANALYZED AND TESTED VS. EACH OPERATIONAL ENVIRONMENT
   (b) WITHOUT COMPROMISING "PERFORMANCE-LIFE"
2. MAXIMUM PERFORMANCE-LIFE MARGINS
   (a) MAXIMUM "END-OF-LIFE" LIMITS IN CIRCUIT DESIGN
   (b) MINIMUM OPERATIONAL "JUNCTION* & CASE" STRESS LEVEL
   (c) MAXIMUM THERMAL CONDUCTIVITY PER POUND
   (d) MAXIMUM CAPABILITY–ENVIRONMENT STRESS VS. TIME

*JUNCTION: CRITICAL ELEMENT IN DOMINANT FAILURE MECHANISM

CHART #VI

II. CRITERIA: (Cont'd)

3. OPTIMUM OPERATIONAL ASSURANCE
   (a) MAXIMUM PRIOR OPERATIONAL EXPERIENCE
      1) EXACT TYPE, PACKAGING & ENVIRONMENT
      2) CLOSELY RELATED TYPE, PKG'G. & ENV.
      3) CONCURRENT, APPLICABLE EVALUATION
      4) MAXIMUM MATERIAL & PROCESS CONTROL
   (b) SIGNIFICANT CONCURRENT DEVELOPMENT
      1) EXACT TYPE, PACKAGING & ENVIRONMENT
      2) CLOSELY RELATED TYPE, PKG'G. & ENV.
      3) CONCURRENT, APPLICABLE EVALUATION
      4) MAXIMUM MATERIAL & PROCESS CONTROL
4. ALTERNATIVE SOURCE DEVELOPMENT
   (a) APPLY EXISTING INVESTMENTS (MERCURY AS AVAILABLE)
   (b) EXTEND TO SPACE ENVIRONMENT
      1) 100% SCREENING, AGING, DATA, ETC.
      2) VACUUM-THERMAL CORRELATION
      3) COMPONENT DESIGN
   (c) ESTABLISH AND EVALUATE ALTERNATE SUPPLIERS

CHART #VII

USE OF TERMS:

1. DERATING: – SVS–2509 – UNLESS OTHERWISE STATED FROM CONVENTIONAL MFGR'S RATINGS
2. SCREENING: – A TEST PROCEDURE WHICH IMPROVES A "LOT" OF PARTS BY DETECTING & REMOVING DEFECTIVE ITEMS (OR POTENTIALLY DEFECTIVE)
3. "AGING": – ENVIRONMENTAL EXPOSURE (WITHOUT POWER BEING APPLIED) FOR A STATED PERIOD & PLAN
   (a) TO STABILIZE
   (b) TO SCREEN
4. "BURN IN": – OPERATION AT OR ABOVE OPERATING POWER LEVELS UNDER STATED ENVIRONMENT, PERIODS & PLAN
   (a) TO STABILIZE
   (b) TO SCREEN
5. "REFEREE" TEST: – AN ARBITRARY SPECIFIC TEST TO COMPARE LIKE PARTS FOR SELECTION
   (a) BETWEEN TYPES & KINDS
   (b) BETWEEN SOURCES

As indicated on Chart VIII, the results of surveys conducted to date of each of the applicable Advent suppliers currently participating in the Minuteman Program, as well as of the surveys of other suppliers of comparably high quality, high reliability parts, indicate that high stability (i.e. lack of change of the essential performance characteristics of the part over the full range of applicable stresses and environments) of the parts as applied in the system is a principal criteria of the selection of preferred parts for the elimination of less dependable alternative items.

Chart IX, while in no degree all-inclusive, is illustrative of the importance of certain application data to be incorporated in each part specification. Of particular note is Item 5 on this chart. This is particularly important, in that the design of space vehicles involves the operation of energized components under vacuum conditions and the proper application of the individual piece parts as packaged is particularly dependent upon the thermal integrity of the design. This can only be

effectively accomplished by a clear definition of the interface of the thermal and electrical characteristics of the part itself as distinct from and in relation to that of the packaging of the part in the equipment design.

Chart X is illustrative of the type of information to be made available to equipment designers by the engineers of the parts manufacturer. The left-hand scale in degrees C is the temperature of the critical element (e.g. the junction of the transistor). The curves on the chart are indicative of the changes in performance characteristic as a combined effect of time, electrical or other stress, and the temperature of the critical element.

Chart XI is illustrative of the correlating application information by which the circuit and equipment designer can assure that the temperature of the case of the piece part as packaged in its vacuum environment is kept within such temperature limits as will maintain the performance characteristics of the part over the life of the mission, as well as over the test period prior to the beginning of the mission.

Chart XII illustrates the project orientation of effort and flow of information from the time the project is definitized to the design of the equipment components by design engineers. As outlined on May 2, 1961, team efforts drawing upon the personnel in each of the operational divisions of the Company and its principal consultants and subcontractors have developed design standards specifications which are made a part of the systems specification in placing specific design requirements, methods, parts and material and application data in accordance with which each element of the system is designed.

Chart XIII indicates the continuing improvement and updating of these specifications as new information is developed and made available.

CHART #VIII

GENERAL RESULTS OF SURVEYS TO DATE:

1. A PREFERRED CRITERIA FOR THE SELECTION OF LONG-LIFE PARTS IS TO SELECT PARTS WHICH HAVE DEMONSTRATED HIGH STABILITY
2. THE RESULTS OF "PROOF", "AGING" AND "BURN-IN" TYPES OF SCREENING TESTS BOTH BY MANUFACTURER & USERS HAVE BEEN TO ESTABLISH PROCESSES & TESTS WHICH SELECT PARTS WITH DEMONSTRATED HIGH STABILITY

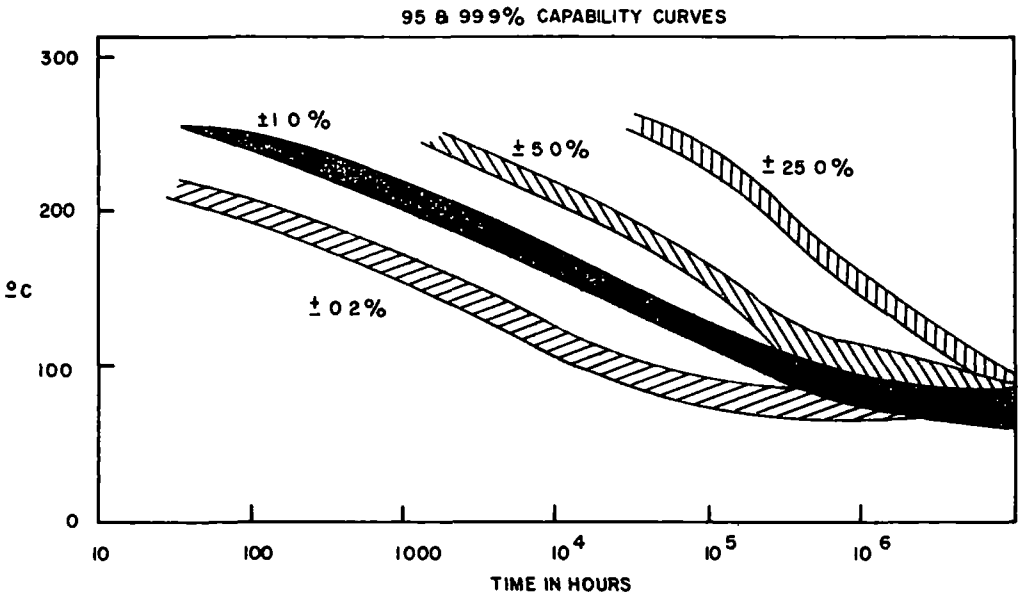
eg: 1. WELDED JOINTS AT CRYSTAL – LOCALE OF HIGH LEAKAGE
2. CONTAMINATION
3. ION MIGRATION
4. OUTGASSING

CHART #IX

APPLICATION DATA
for
SATELLITE ELECTRONIC PARTS

1. DIMENSIONS & TOLERANCES
2. PART WEIGHT – In Lbs (to nearest 3 Figures) of body of part + 1/4" Leads or Equiv.
3. MATERIALS – Including Leads & Coatings...
   (a) External to (Glass/Metal/Ceramic) Hermetic Seal
   (b) Internal to (Glass/Metal/Ceramic) Hermetic Seal
   ...to assure Vacuum/Radiation/Packaging Integrity
4. STRESS VS. PERFORMANCE – LIFE
   Jointly
   (a) Electrical Ratings vs. Life & Stability
      1. Correlation: "Ambient" to "Conduction"
   (b) Thermal Stress vs. Life & Stability
      1. Critical Element Temperature (Activation Energy)
      2. Conductivity – Critical element to case... (ΔT vs. Power Level)
      ...as packaged for space
   (c) Shock, Vibration, Humidity, Corrosion, Fungus, Dust, etc.
5. INTERFACE DEFINITIZATION:
   (a) Electronic Part to Circuit Design
      At Electrical Leads
   (b) Electronic Part to "Package" Design
      At Case with Heat Dissipation as Packaged –SVS–2509

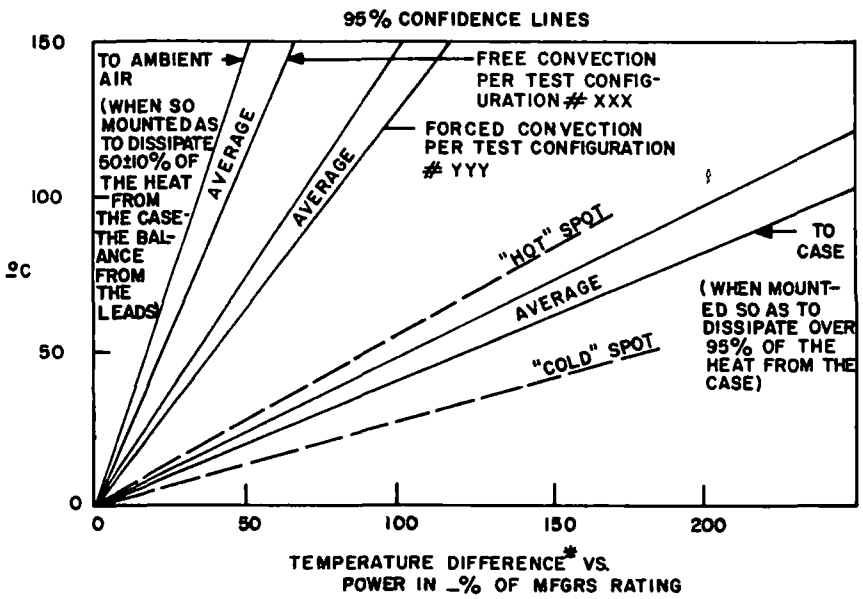
CHART #X



LIFE * VS TEMPERATURE OF ACTIVE ELEMENT

* AS MEASURED BY - % CHANGE IN PERFORMANCE CHARACTERISTIC

CHART #XI



*BETWEEN ACTIVE ELEMENT & REFERENCED "PACKAGING INTERFACE"

CHART #XII

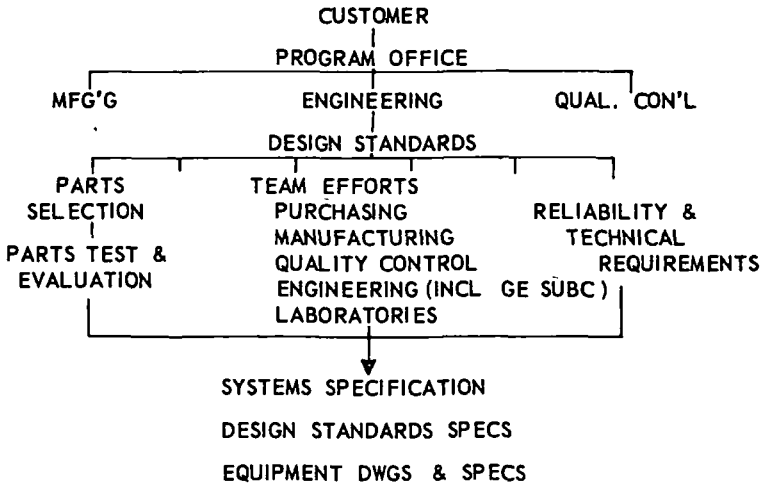


CHART #XIII

ADVENT
DESIGN STANDARDS DEVELOPMENT

GROUND BASED EQUIPMENT
GSSE – JOE BLACK

SPACE VEHICLE EQUIPMENT
ELECTRO-MECHANICAL – H ESTEN
SVS–2690 STRUCTURAL – R R WALLACE
ELECTRONIC
SVS–2691 CIRCUIT DESIGN – (S CHARP) R. KERN
SVS–2692 PARTS SELECTION – J STANTON
SVS–2509 PACKAGING – (J. DURYEA) B HATCH
TEST & EVALUATION – T WALSH

RESPONSIBILITIES & RELATIONSHIPS
GSSE DESIGN STANDARDS

SCOPE COMPLETE FOR ALL GROUND BASED EQUIPMENT
EMPHASIS
TREND TEST CIRCUITRY
"WORST CASE" ANALYSIS
SELF-VERIFICATION CHECKING
MARGINAL PREDICTION CIRCUITRY
RELIABILITY – MAINTAINABILITY – LOGISTICS
TEMPERATURE & VOLTAGE DERATING LIMITS
PARTS – MATERIALS – PACKAGING

TEAM. JOE BLACK
Frank Visich
Joe Scarcelli
Tom Cota
Ralph Santoro, Mfg
Ed Smith Q C
J Youtcheff R &T R
H J Smile

Chart XIV outlines the basic assumptions of this effort, namely:

1. That there is a design answer to the Performance-Life problem; that the wide variance of presently available failure rate data is occasioned by the equally great variance in details of engineering practice and in manufacturing and operational practices on the equipments and systems from which the data has been drawn.

2. That Stress-Time "threshold values" for equipment design exist in nature not only in the mechanical materials area, but in every area of design activity, and that by designing each element of the system to assure that all "Stress-Time" levels are below these thresholds an answer to the design life problem of 1 year to 3 years, or even to 5 years or 10 years, can be found.

3. That by proceeding with the more concentrated effort in each of the operations of Engineering, Manufacturing and Quality Control, the variance in part and material performance with time (that has obscured the approach to these long life problems and that has made many doubt the existance of any real answer to the problem) can be adequately controlled in practice, that this control can be made effective by consistency and uniformity in the engineering design effort, and by equally intensive efforts in each of the other operations involved in selection, purchase, acceptance, screening, handling, fabrication, assembly, test and inspection, shipment and field both at launch and during the orbit period.

Chart XV indicates the course of early development of such a program Task teams would be formed for the Apollo Program giving particular attention to the specific requirements of the program. These will be directly analogous to those previously indicated for Advent, except insofar as the Apollo system adds to the effort areas, e.g. Design Standards involving human factors considerations.

CHART #XIV

ASSUMPTIONS

1. THAT THERE IS A DESIGN ANSWER TO THE PERFORMANCE-LIFE PROBLEM
2. THAT "THRESHOLD" VALUES EXIST IN NATURE
3. THAT VARIANCE CAN BE ADEQUATELY CONTROLLED IN PRACTICE

CHART #XV

ACTIONS

1. CONCENTRATION ON AREAS OF GREATEST RISK
2. RE-EXAMINATION OF ENGINEERING FUNDAMENTALS
3. TASK TEAMS
   - A. TO MAKE IMMEDIATE SELECTIONS
   - B. TO ESTABLISH DESIGN APPLICATION METHODS
   - C. TO EVALUATE AND SCREEN SELECTIONS, INCLUDING:
     - (1.) LIFE STRENGTH THRESHOLDS AND VARIANCE
     - (2.) LIFE DEGRADATION THRESHOLDS AND VARIANCE

Charts XVI, XVII, XVIII, XIX, XX, XXI illustrate the test and exploratory and evaluation effort being undertaken on Advent, details of which were covered in the presentation on May 2, 1961.

Chart XXII is indicative of the test categories in each program. Exploratory evaluation tests provide engineering design data, acceptance and screening tests provide production assurance of the extremely high quality and reliability of the actual parts incorporated into final mission hardware.

Chart XXIII illustrates the task force plan involved in parts selection. Path A, B, C and D illustrate the progressive refinement and definitization of engineering requirements to establish the minimum number of different types and kinds of functional component parts. A', B', C' and D' illustrate the corresponding definitization of available parts knowledge (including any improvement programs). The screening and evaluation of these two areas of information result in the determination of the specific list of the minimum number of component parts types applicable to APOLLO Project. The design of all components will be restricted to these parts and materials, and to the incorporation of them into the design in strict accordance with the "application data" established for the APOLLO Project.

Chart XXV illustrates the results to date on the Advent Program. It is expected that parts peculiar to the APOLLO Program will be on this same order of magnitude.

Chart XXVI is indicative of areas of concentration of effort on such a parts program.

Chart XXVII and XXVIII indicate the presentation made May 2, 1961 of the recently developed "Weibull" data applicable to the Advent parts and generally considered to be applicable to any long-lived space vehicle. While not of particular emphasis during the mission of APOLLO, it is of significance to the program as a whole, as indicated on these charts, together with the following charts XXIX and XXX.

CHART #XVI

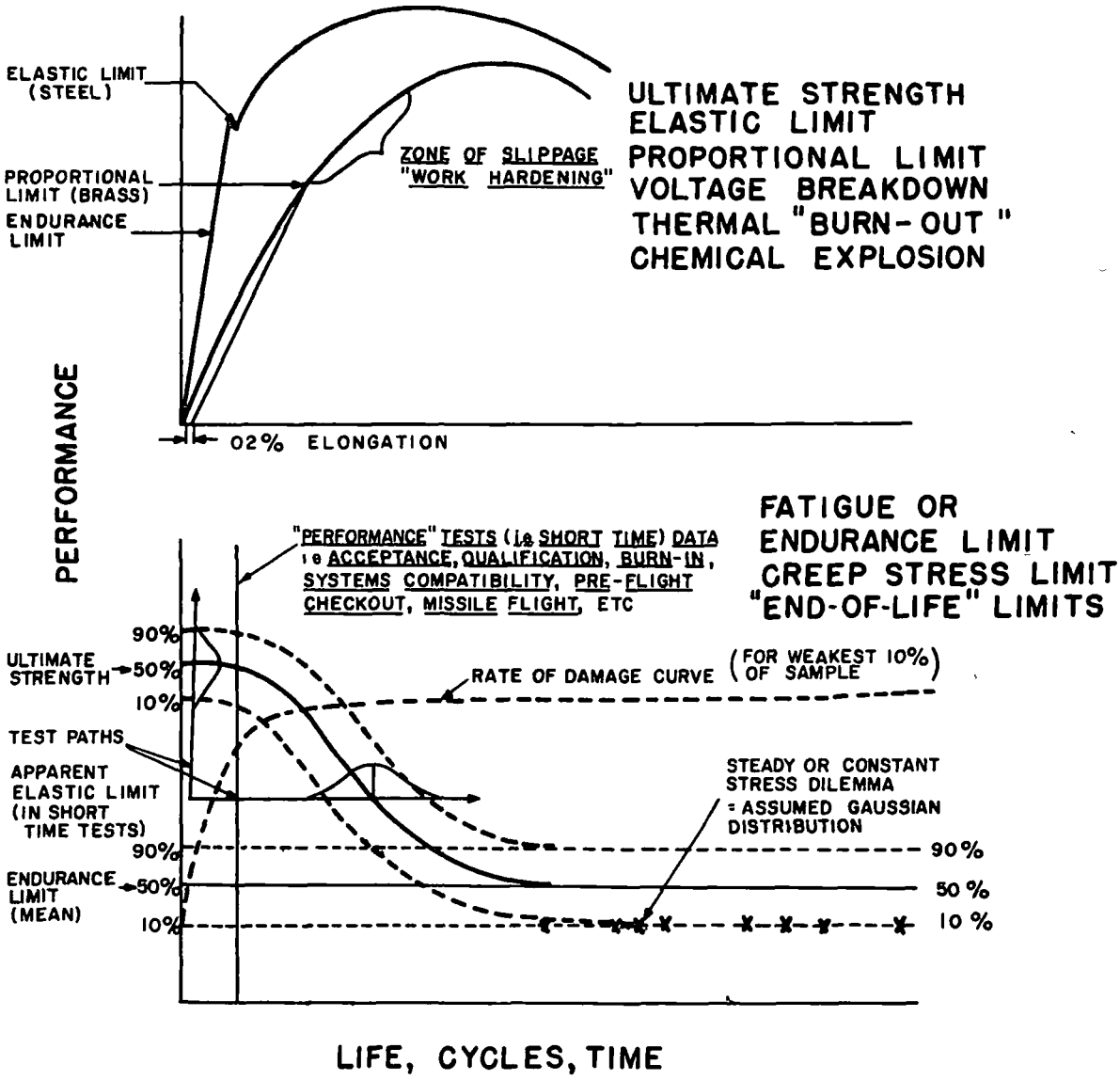

ELASTIC LIMIT (STEEL)
PROPORTIONAL LIMIT (BRASS)
ENDURANCE LIMIT
ZONE OF SLIPPAGE "WORK HARDENING"
ULTIMATE STRENGTH
ELASTIC LIMIT
PROPORTIONAL LIMIT
VOLTAGE BREAKDOWN
THERMAL "BURN-OUT"
CHEMICAL EXPLOSION
PERFORMANCE
02% ELONGATION
"PERFORMANCE" TESTS (i.e. SHORT TIME) DATA i.e. ACCEPTANCE, QUALIFICATION, BURN-IN, SYSTEMS COMPATIBILITY, PRE-FLIGHT CHECKOUT, MISSILE FLIGHT, ETC
FATIGUE OR ENDURANCE LIMIT
CREEP STRESS LIMIT
"END-OF-LIFE" LIMITS
ULTIMATE STRENGTH
90%
50%
10%
RATE OF DAMAGE CURVE (FOR WEAKEST 10% OF SAMPLE)
TEST PATHS
APPARENT ELASTIC LIMIT (IN SHORT TIME TESTS)
STEADY OR CONSTANT STRESS DILEMMA = ASSUMED GAUSSIAN DISTRIBUTION
ENDURANCE LIMIT (MEAN)
90%
50%
10%
90%
50%
10%
LIFE, CYCLES, TIME

CHART #XVII

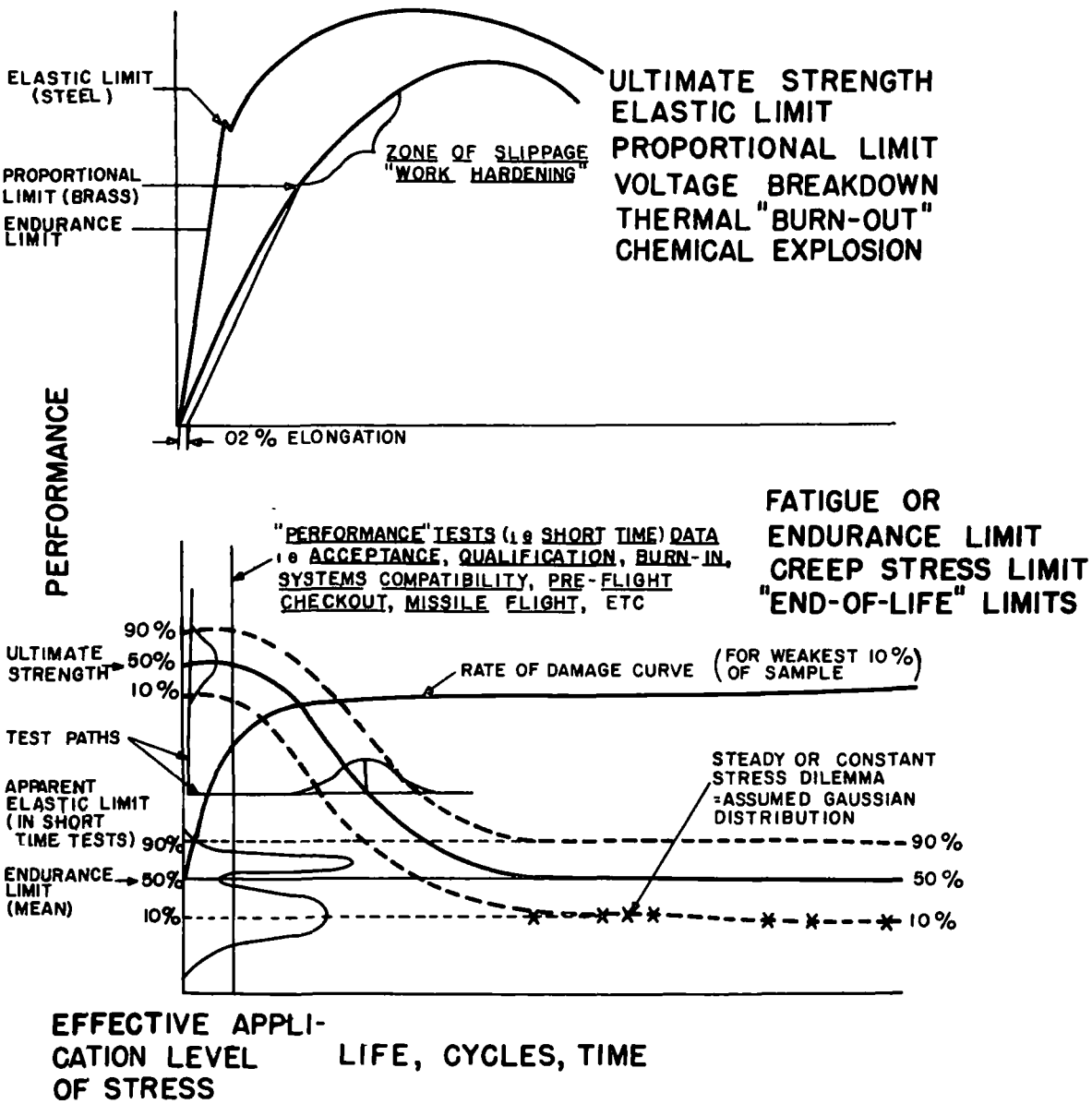

ELASTIC LIMIT (STEEL)
PROPORTIONAL LIMIT (BRASS)
ENDURANCE LIMIT
ZONE OF SLIPPAGE "WORK HARDENING"
ULTIMATE STRENGTH
ELASTIC LIMIT
PROPORTIONAL LIMIT
VOLTAGE BREAKDOWN
THERMAL "BURN-OUT"
CHEMICAL EXPLOSION
02 % ELONGATION
PERFORMANCE
"PERFORMANCE" TESTS (i e SHORT TIME) DATA
i e ACCEPTANCE, QUALIFICATION, BURN-IN, SYSTEMS COMPATIBILITY, PRE-FLIGHT CHECKOUT, MISSILE FLIGHT, ETC
FATIGUE OR ENDURANCE LIMIT
CREEP STRESS LIMIT
"END-OF-LIFE" LIMITS
90 %
ULTIMATE STRENGTH 50%
10 %
RATE OF DAMAGE CURVE (FOR WEAKEST 10 % OF SAMPLE)
TEST PATHS
APPARENT ELASTIC LIMIT (IN SHORT TIME TESTS) 90%
ENDURANCE LIMIT (MEAN) 50%
10%
STEADY OR CONSTANT STRESS DILEMMA =ASSUMED GAUSSIAN DISTRIBUTION
90 %
50 %
10 %
EFFECTIVE APPLICATION LEVEL OF STRESS
LIFE, CYCLES, TIME

CHART #XVIII

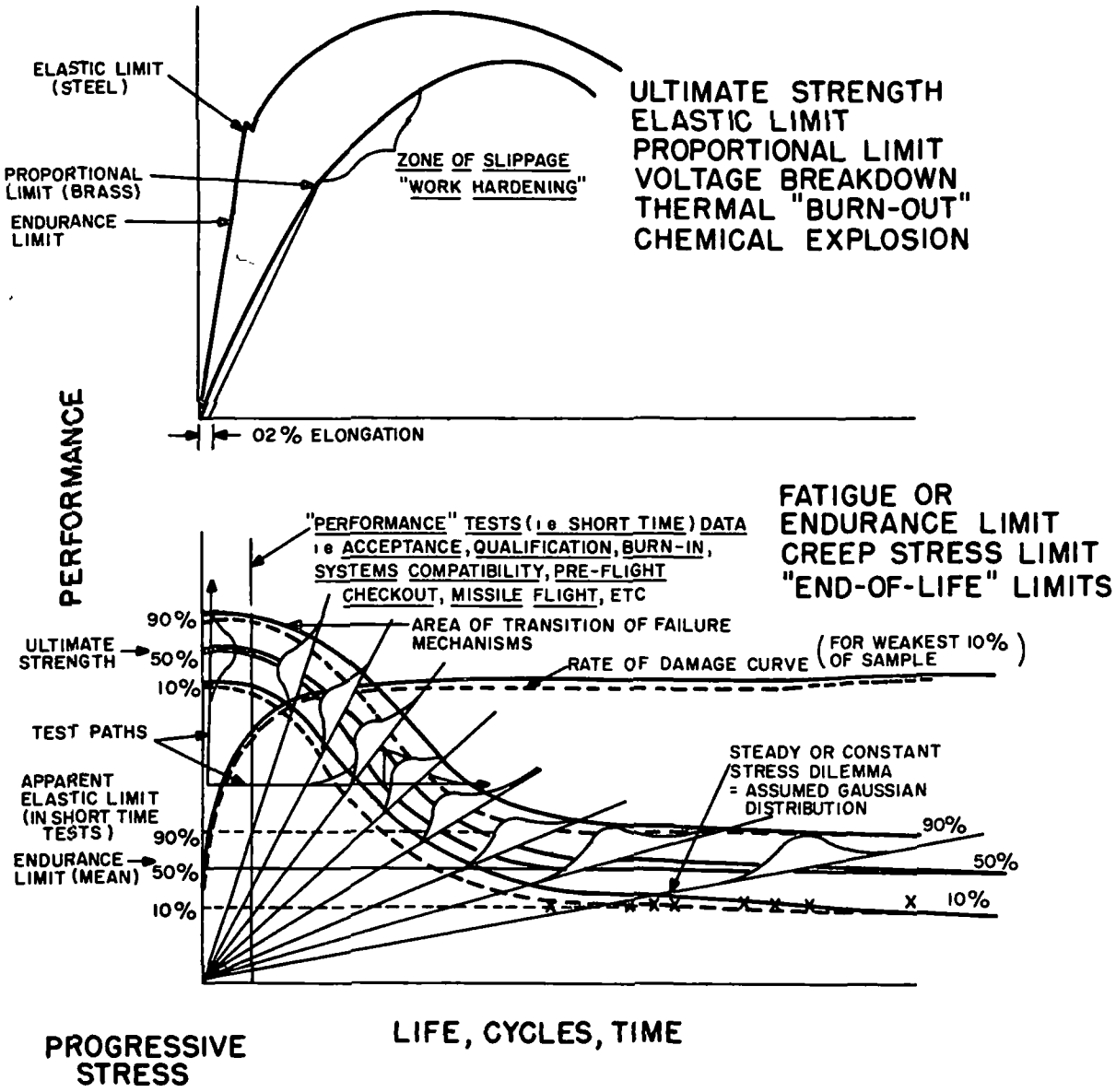

ELASTIC LIMIT (STEEL)
PROPORTIONAL LIMIT (BRASS)
ENDURANCE LIMIT
ZONE OF SLIPPAGE "WORK HARDENING"
ULTIMATE STRENGTH
ELASTIC LIMIT
PROPORTIONAL LIMIT
VOLTAGE BREAKDOWN
THERMAL "BURN-OUT"
CHEMICAL EXPLOSION
02% ELONGATION
PERFORMANCE
"PERFORMANCE" TESTS (i e SHORT TIME) DATA i e ACCEPTANCE, QUALIFICATION, BURN-IN, SYSTEMS COMPATIBILITY, PRE-FLIGHT CHECKOUT, MISSILE FLIGHT, ETC
FATIGUE OR ENDURANCE LIMIT
CREEP STRESS LIMIT
"END-OF-LIFE" LIMITS
AREA OF TRANSITION OF FAILURE MECHANISMS
RATE OF DAMAGE CURVE (FOR WEAKEST 10% OF SAMPLE)
ULTIMATE STRENGTH
90%
50%
10%
TEST PATHS
APPARENT ELASTIC LIMIT (IN SHORT TIME TESTS)
ENDURANCE LIMIT (MEAN)
STEADY OR CONSTANT STRESS DILEMMA = ASSUMED GAUSSIAN DISTRIBUTION
PROGRESSIVE STRESS
LIFE, CYCLES, TIME

CHART #XIX

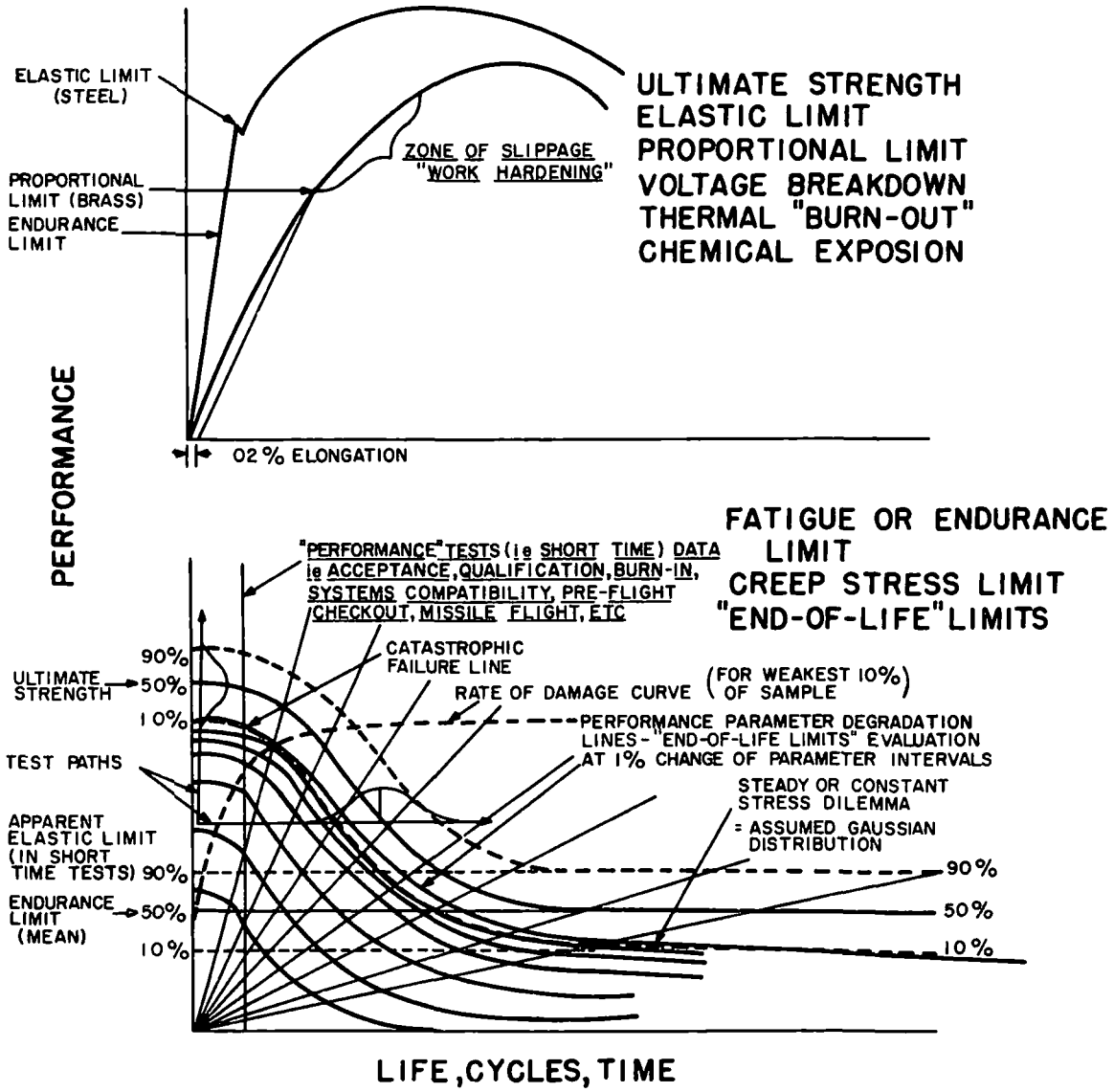
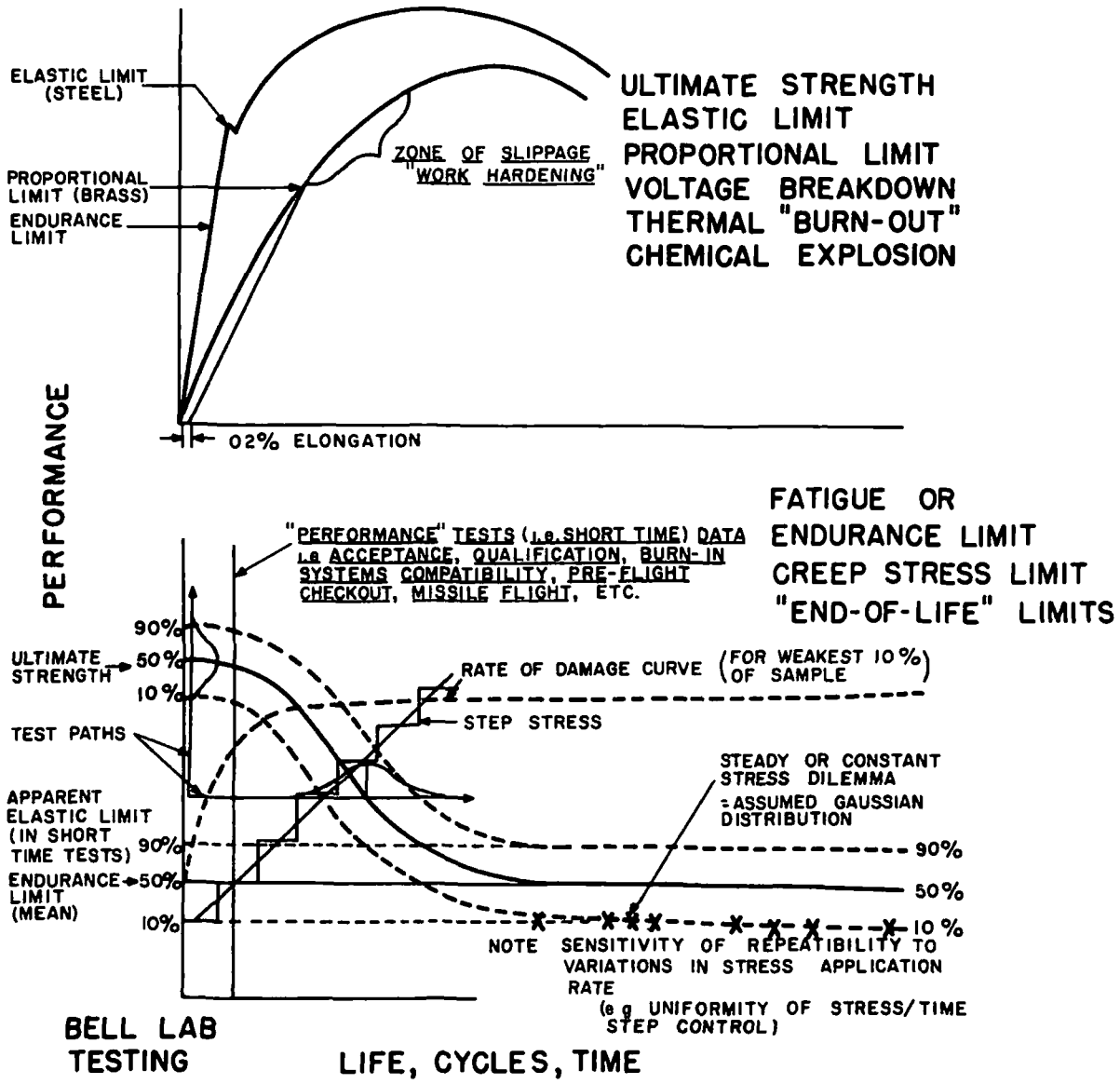

ELASTIC LIMIT (STEEL)
PROPORTIONAL LIMIT (BRASS)
ENDURANCE LIMIT
ZONE OF SLIPPAGE "WORK HARDENING"
ULTIMATE STRENGTH
ELASTIC LIMIT
PROPORTIONAL LIMIT
VOLTAGE BREAKDOWN
THERMAL "BURN-OUT"
CHEMICAL EXPOSION
PERFORMANCE
02 % ELONGATION
FATIGUE OR ENDURANCE LIMIT
CREEP STRESS LIMIT
"END-OF-LIFE" LIMITS
"PERFORMANCE" TESTS (ie SHORT TIME) DATA ie ACCEPTANCE, QUALIFICATION, BURN-IN, SYSTEMS COMPATIBILITY, PRE-FLIGHT CHECKOUT, MISSILE FLIGHT, ETC
CATASTROPHIC FAILURE LINE
RATE OF DAMAGE CURVE (FOR WEAKEST 10% OF SAMPLE)
PERFORMANCE PARAMETER DEGRADATION LINES - "END-OF-LIFE LIMITS" EVALUATION AT 1% CHANGE OF PARAMETER INTERVALS
STEADY OR CONSTANT STRESS DILEMMA
= ASSUMED GAUSSIAN DISTRIBUTION
ULTIMATE STRENGTH
TEST PATHS
APPARENT ELASTIC LIMIT (IN SHORT TIME TESTS)
ENDURANCE LIMIT (MEAN)
90%
50%
10%
LIFE, CYCLES, TIME

CHART #XX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PROPORTIONAL LIMIT (BRASS)
ENDURANCE LIMIT
ZONE OF SLIPPAGE "WORK HARDENING"
ULTIMATE STRENGTH
ELASTIC LIMIT
PROPORTIONAL LIMIT
VOLTAGE BREAKDOWN
THERMAL "BURN-OUT"
CHEMICAL EXPLOSION
02% ELONGATION
PERFORMANCE
"PERFORMANCE" TESTS (i.e. SHORT TIME) DATA i.e ACCEPTANCE, QUALIFICATION, BURN-IN SYSTEMS COMPATIBILITY, PRE-FLIGHT CHECKOUT, MISSILE FLIGHT, ETC.
FATIGUE OR ENDURANCE LIMIT
CREEP STRESS LIMIT
"END-OF-LIFE" LIMITS
90%
ULTIMATE STRENGTH 50%
10%
RATE OF DAMAGE CURVE (FOR WEAKEST 10% OF SAMPLE)
STEP STRESS
TEST PATHS
STEADY OR CONSTANT STRESS DILEMMA
= ASSUMED GAUSSIAN DISTRIBUTION
APPARENT ELASTIC LIMIT (IN SHORT TIME TESTS) 90%
ENDURANCE LIMIT (MEAN) 50%
10%
90%
50%
10%
NOTE SENSITIVITY OF REPEATIBILITY TO VARIATIONS IN STRESS APPLICATION RATE
(e.g. UNIFORMITY OF STRESS/TIME STEP CONTROL)
BELL LAB TESTING
LIFE, CYCLES, TIME

CHART #XXI

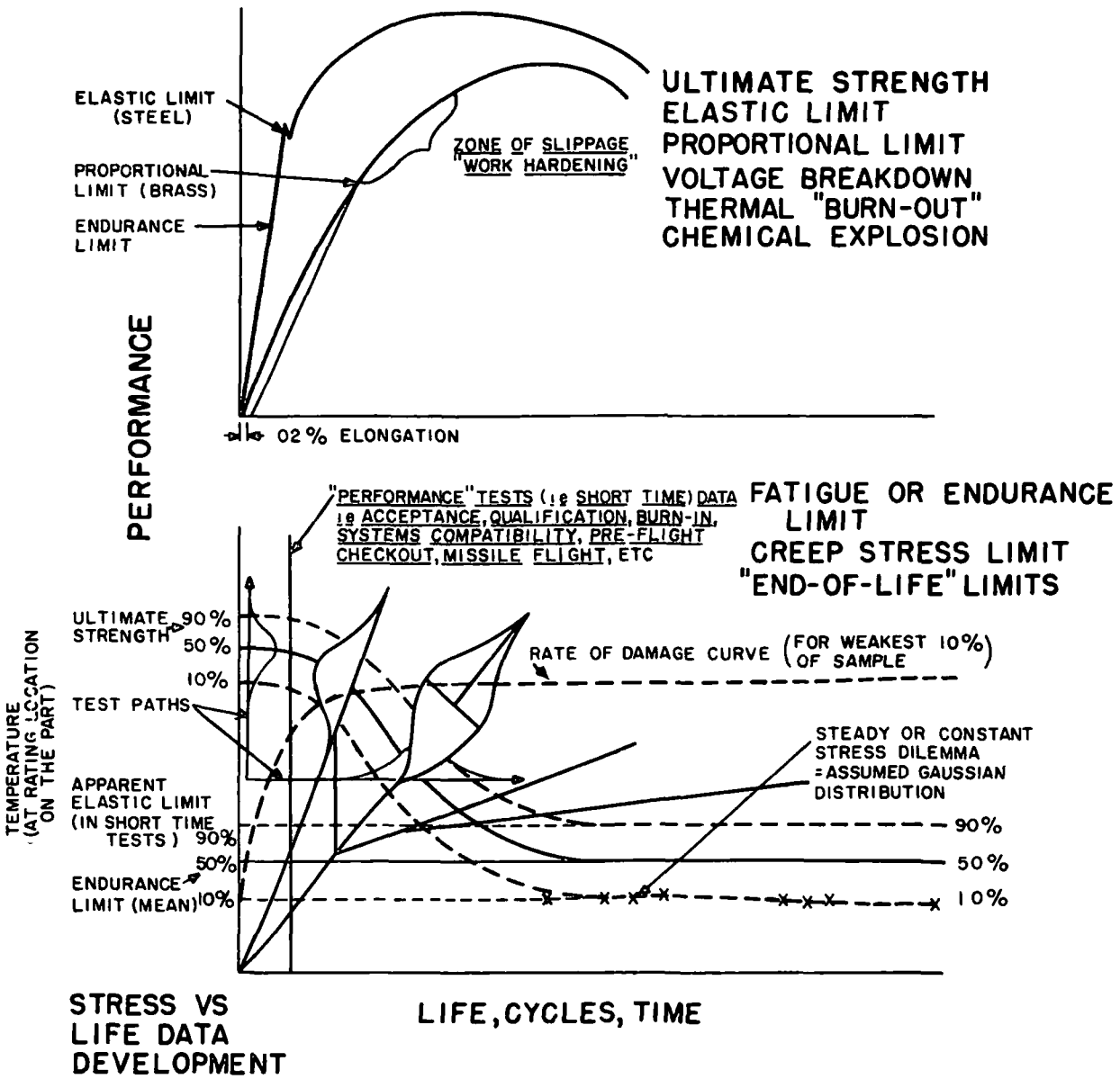


CHART #XXII

TYPES OF TESTING

- EXPLORATORY
- EVALUATION
- ACCEPTANCE
- SCREENING

CHART #XXIII

COMPONENT PARTS TASK FORCE MASTER PLAN

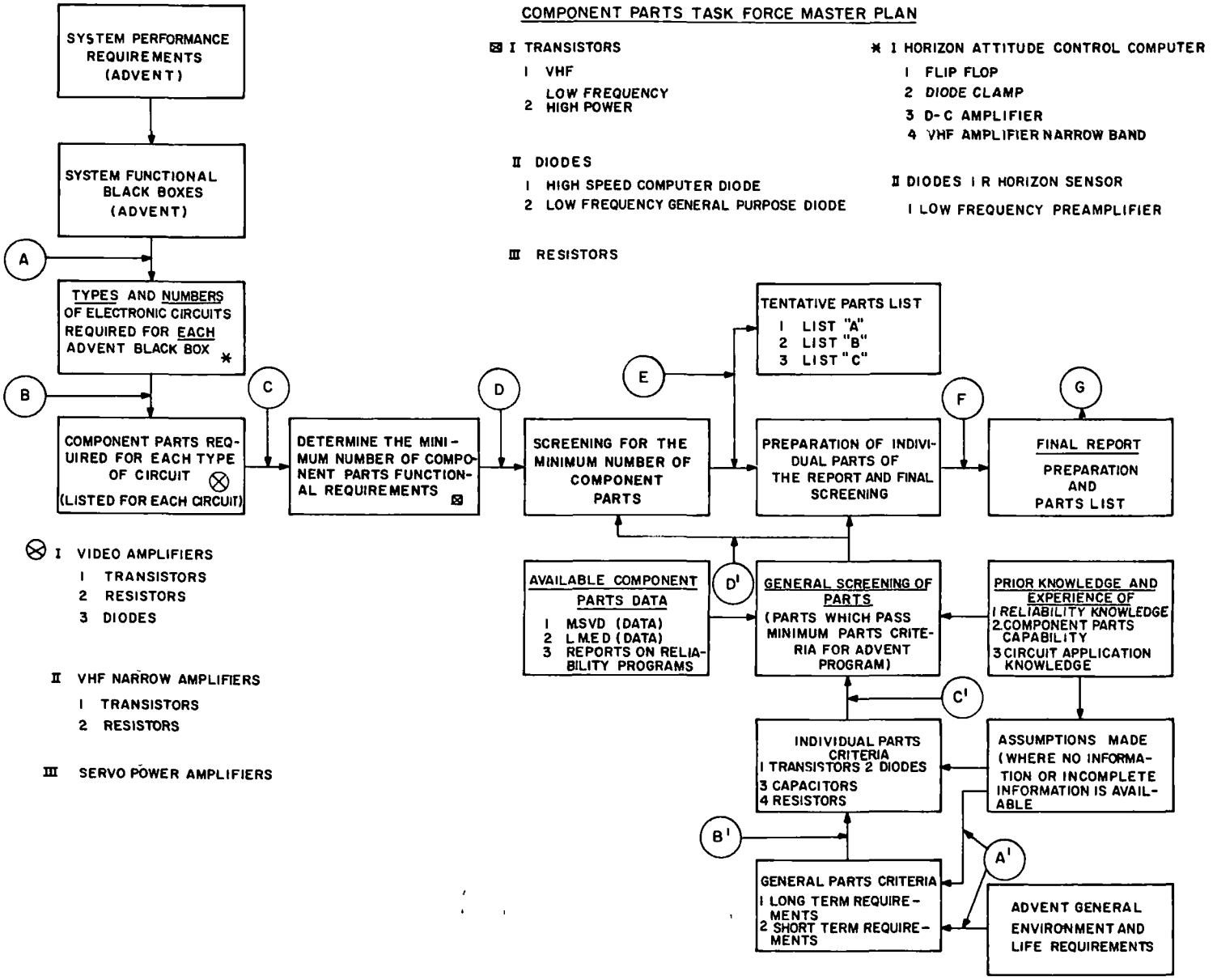


CHART #XXV

A. DESIGN LIST	EFFORT	RESULT
1. TRANSISTORS	N > 2000 (1088)	9 TYPES
2. DIODES	N > 4000 (1500)	7 TYPES
3. CAPACITORS		4 TYPES
4. RESISTORS		3 TYPES

B. REPORTS

1. A PIR FOR 1 → 4 ABOVE
2. A REPORT 1 → 4 ABOVE
3. ADVENT SYSTEM SPECIFICATION

CHART #XXVI

FAILURE FREE LIFE DESIGN DATA

SCREENING — AT MANUFACTURER & USER TO BEST USE OF FACILITIES

DERATING — TO OPTIMAL WEIGHT-LIFE TRADE-OFF

LIFE TESTING — TO VERIFY DESIGN DATA

vs

ENVIRONMENT
- VACUUM (SEAL)
- RADIATION (MATERIALS)
- TEMPERATURE (CHARACTERISTICS)

&

APPLICATION
- LAUNCH (LEAD-JOINTS)
- ORBIT (LONG LIFE UNDER COMBINED VOLTAGE-TEMP-VACUUM-RAD STRESSES)

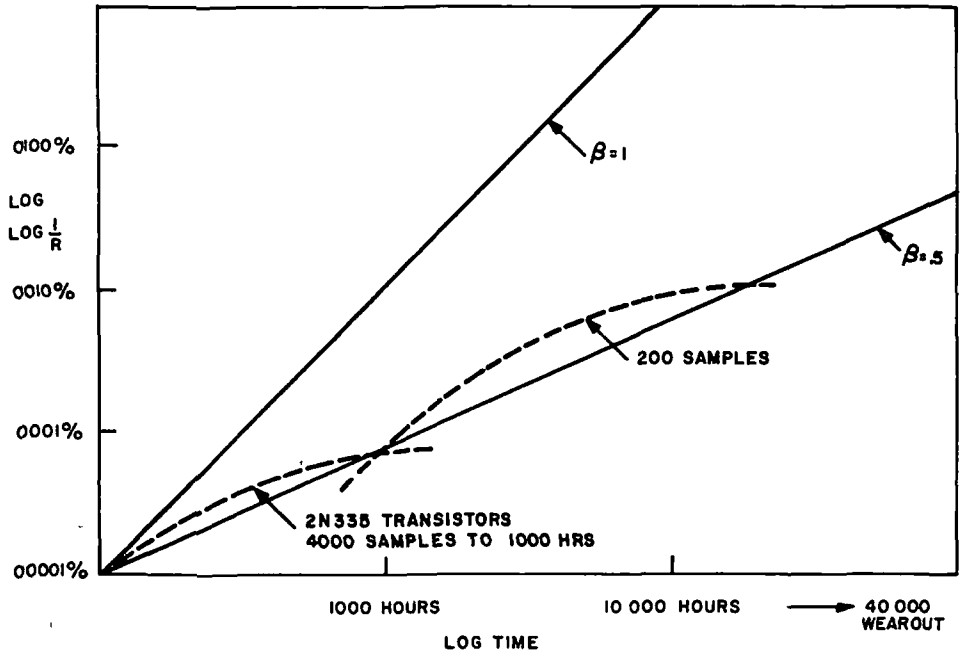
RE-ENTRY VEHICLES

MANNED & UNMANNED SPACE VEHICLES

ANCILLARY SPACE EQUIPMENT

CHART #XXVII

FAILURE ANALYSIS



GEL

MICA CAPACITORS -

A 2500 SAMPLES

B 2000 HOURS

C VARIOUS VOLTAGE LEVELS

1000 β = 5

6000 β = 45

WEIBULL

NORMAL

EXTREME VALUE

} CUMULATIVE RECORD OF TIMES TO FAILURE

1 FOR THE SPECIFIC PART

2 IN ITS AS PACKAGED AS APPLIED ENVIRONMENT

3 WITH ADEQUATE INSTRUMENTATION OF ALL "STRESSES"

- A TEMPERATURE CASE NOT AMBIENT
- B VOLTAGES
- C VACUUM
- D RADIATION

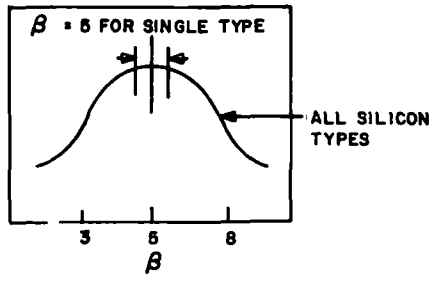
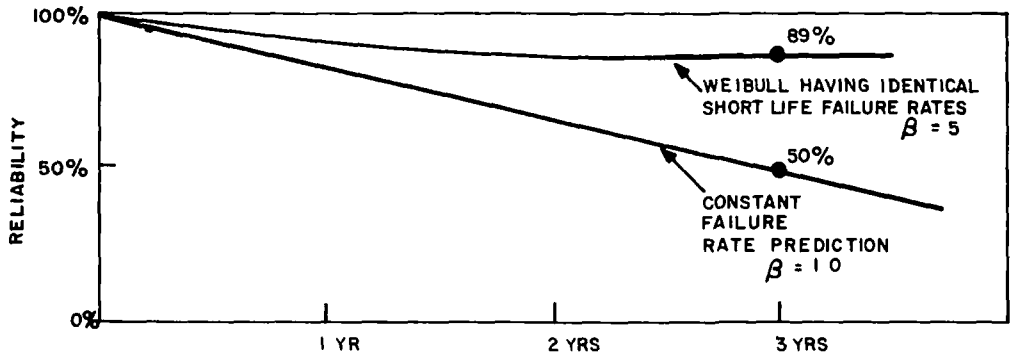


CHART #XXVIII

SIGNIFICANCE OF WEIBULL



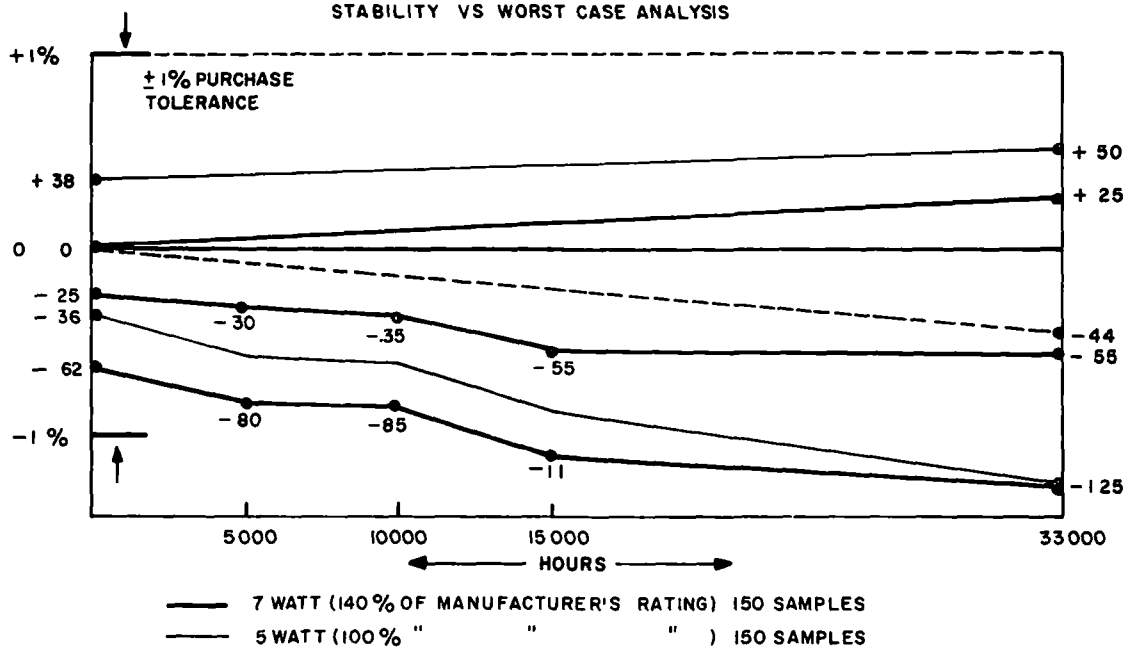
1 NOT IMPORTANT FOR SHORT LIFE APPLICATIONS (EG- UNDER 1000 HOURS)

2 OF VITAL IMPORTANCE IN THE ECONOMY OF LONG LIFE SATELLITE APPLICATIONS

IN RAW DATA - HISTORY OF TIMES TO INDIVIDUAL FAILURES IS IMPORTANT

CHART #XXIX

STABILITY VS WORST CASE ANALYSIS



TESTS AT 20%, 40%, 60%, 80%, 100%, 120%, 140% FOR 150 LOT (SAMPLES) 1200 UNITS FOR 33000 HRS

SHOWED: NO CATASTROPHICS

NO DRIFT BEYOND ± 5% - MEDIAN LIFE 550,000 HOURS

$\frac{3}{1200}$ UNITS (140%, ETC) BEYOND ± 3%

=.0083% / 1000 HRS OR

=MTTF 375,000 HRS

NO UNIT DRIFT BEYOND ± 2% AT 60% OF RATING

COVAR LEADS - HERMETIC SEALS (GLASS TO METAL) (WELDED ELECTRICAL LEADS BY USER)

RAW DATA BEING OBTAINED TO EXAMINE "WEIBULL"

CHART #XXX

TEST EFFICIENCY

1. TRUNCATION OF LIFE TESTING {SOME LOTS}
   TO APPROX. 25% FAILURES POINT PERMITS
   ACCURATE EXTRAPOLATION (IF MICA CAPACITOR
   DATA IS INDICATIVE FOR β = .45 TO .55)
   USING WEIBULL PLOTTING METHODS
2. ADEQUATE INSTRUMENTATION & CONTROL OF
   SIGNIFICANT TEST PARAMETERS PROVIDES
   USEFUL RESULTS

   eg.

   PART NEAREST BLOWER – 12,000 HOURS

   PART FURTHEST FROM BLOWER – 2,000 HOURS

   (TO 1ST "DRIFT" BEYOND 2% @ 200% LOAD)

Chart XXXII summarizes the parts and materials approach as presented to NASA May 2, 1961. The experimental data that has been developed under the Advent Program in the areas of packaging, parts, circuit design, mechanical and electro-mechanical items, structural design, evaluation and test, thermal integrity and failure rates reliability analyses was also presented to the NASA team during the first week in May. It is intended that this definitive, meticulous, thorough engineering approach will be applied to every aspect of the APOLLO system. The reliability objective of these efforts is that of 100 percent failure free life during the APOLLO mission and during the subsequent program elements to which portions of the APOLLO Program may later be directed.

While it is recognized that the degree of confidence that can be established in any system or equipment design, whether manned or unmanned, is dependent upon the statistical scope and physical significance of the testing and operational programs

undertaken and evaluated, the recognition of such statistical limitations shall not be permitted to modify or compromise the meticulous attention which must be given to actual engineering design under all aspects of this program. It is recommended that extensive life tests of all parts peculiar and of all components peculiar to the APOLLO project be incorporated into this program to the maximum degree permitted by the program schedule. All indications to date would confirm that the immediate benefits both in the quality of the equipment and system development and in the confidence with which it can be applied to the mission will be significantly improved by such a program.

CHART #XXXII

FAILURE-FREE LIFE

1. BY RESTRICTING OUR DESIGN TO PARTS OF KNOWN STABILITY, QUALITY & MANUFACTURED CONSISTENCY.
2. BY APPLYING ENVIRONMENTALLY CORRELATED APPLICATION DATA IN DESIGN.
3. BY CONTROLLING THE ENVIRONMENT & LOADINGS, THE MATERIALS MUST SUSTAIN TO LEVELS AT WHICH FAILURE IS A DEGRADATION PROCESS.
4. BY DERATING TO ATTAIN ADEQUATE LIFE-PERFORMANCE PROBABILITY.
5. BY INCORPORATING IN CIRCUIT AND PACKAGING ADEQUATE TOLERANCE ALLOWANCES (eg., Worst Case Design)

B Capabilities and Related Experience

1.0 GENERAL ELECTRIC COMPANY-MISSILE AND SPACE VEHICLE DEPARTMENT (GE-MSVD) CAPABILITIES

The other volumes of this study demonstrate GE-MSVD capability for preliminary design on the complex APOLLO space system, while this volume illustrates GE-MSVD ability to manage, integrate, design, develop, manufacture, test and support the forthcoming hardware program. This appendix will give NASA data on another primary criteria needed to evaluate the GE-MSVD capability to develop the APOLLO system. This is proven, successful experience on past and present complex hardware systems. This data includes:

1. Present GE-MSVD management and organization.
2. Hardware experience which can be applied to the APOLLO program.
3. Facility capability.

1.1 GENERAL ELECTRIC COMPANY-MISSILE AND SPACE VEHICLE DEPARTMENT MANAGEMENT AND ORGANIZATION

1.1.1 Corporate Management and Organization

The Missile and Space Vehicle Department is one of the decentralized operating departments of the General Electric Company and maintains its headquarters in Philadelphia, Pennsylvania. Figure B-1 shows how responsibility and authority is channeled from the Executive Office to the General Manager for the conduct of the business of the Missile and Space Vehicle Department.

Under the concept of decentralization, General Electric Company total business has been divided and assigned to diversified operating departments. Each department is organized, financed and staffed to achieve competitive and effective leadership in its particular product line. In discharging the responsibility of such a decentralized business component, the General Manager of MSVD, Mr. H. W. Paige,

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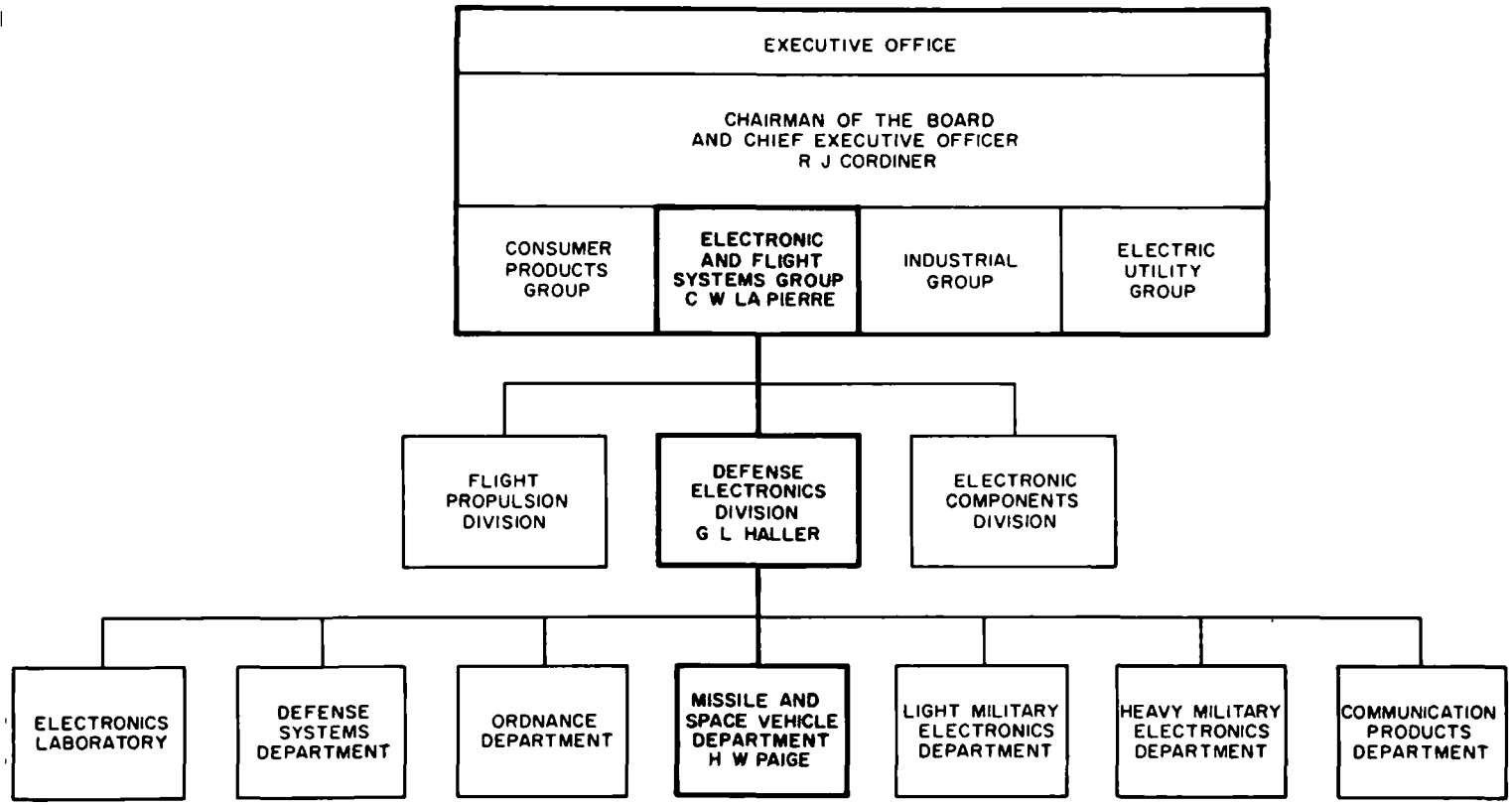

Figure B-1. Present General Electric Company corporate organization chart

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has all the authority commensurate with a complete business responsibility and is held accountable for the results achieved.

In the conduct of the APOLLO program, NASA will have this advantage of the compact, responsive and versatile organization backed by the financial posture and the diversified resources, capabilities and talents of the General Electric Company. Figure B-2 shows other GE departments and laboratories which are geographically adjacent to MSVD and which will contribute directly to the APOLLO program on a continuing basis.

It has been this unique combination of a compact operating department supported by the facilities of a huge company which has enabled MSVD to establish a proven record of accomplishment in the space vehicle field. This record encompasses all aspects of the aerospace business from system management and integration through space vehicle design and development to the manufacture, test and timely delivery of the hardware. This MSVD record of accomplishment includes successfully completed programs on the Thor and Atlas re-entry vehicles, the Discoverer recoverable satellite, and he NERV, Space Laboratory, RVX-1, RVX-2 and RVX-2A and Mark 3C TP experimental space vehicles. Present system-level programs being successfully developed include the Titan and Skybolt re-entry vehicles, the Nike-Zeus target vehicle and the Advent, Samos, Nimbus long life satellites.

1.1.2 Missile and Space Vehicle Department Management and Organization

The Missile and Space Vehicle Department is organized to combine functional operating components with a strong program office for each individual program. Since each functional operating component accomplishes its technical work for all programs, a higher level of competence is maintained than could be supported by any single program. This type of horizontal organization also permits each functional component to grow based on the knowledge and experience gained from related programs. The program office, on the other hand, is organized vertically so that it can direct and control the functional components to meet the specific

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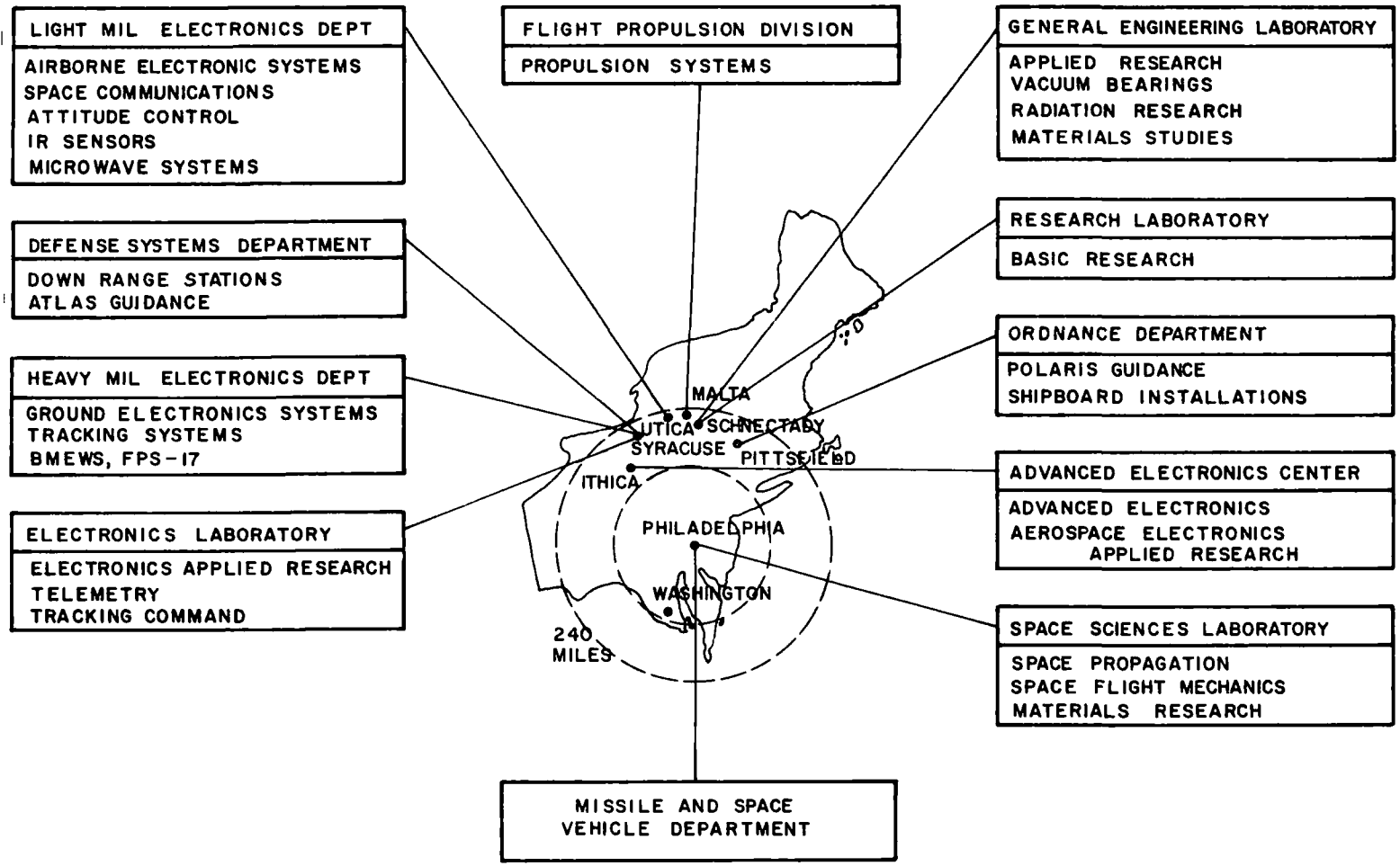

Figure B-2. General Electric Company resources available for APOLLO

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requirements of a single program. MSVD lines of administrative responsibility and functional direction are shown on the organization chart of Figure B-3. The APOLLO program manager will be responsible to plan, integrate, monitor and control the program to meet APOLLO requirements, schedules and costs. To enable him to accomplish this, the program manager will have a staff of managers supported by personnel assigned from the existing support functions and functional operating components as described in detail earlier in this volume (Section 3.0).

The Space Sciences Laboratory which conducts a continuing program of research and advanced development in flight mechanics, space physics, thermodynamics, thermochemistry, aerodynamics, life support systems, and materials will assign personnel to work on specific APOLLO assignments during the growth phase.

The Engineering and Advanced System Engineering Operations will assign to the APOLLO project the necessary technical and scientific personnel, and facilities required to perform system analysis and to design, develop and test the subsystems and components for the APOLLO system.

The MSVD Development Manufacturing Operation is tailored specifically to the requirements of high quality, complex equipments and vehicles on a custom fabrication basis. This capability has enabled MSVD to ship on time hardware which is constantly undergoing development modifications. Necessary personnel, services and facilities will be assigned to APOLLO to perform source selection and purchasing, subcontracting, producibility engineering, tooling and lofting, production control, fabrication and assembly.

The Quality Control and Test Operation has been organized on a level equal with engineering and manufacturing to assure that attention and emphasis will be placed on the critical areas of reliability and quality assurance. This operation is responsible to ascertain that the quality and reliability of materials, processes, components, subsystems and systems meet all program requirements from conception through flight test to operational use. Personnel, services and facilities

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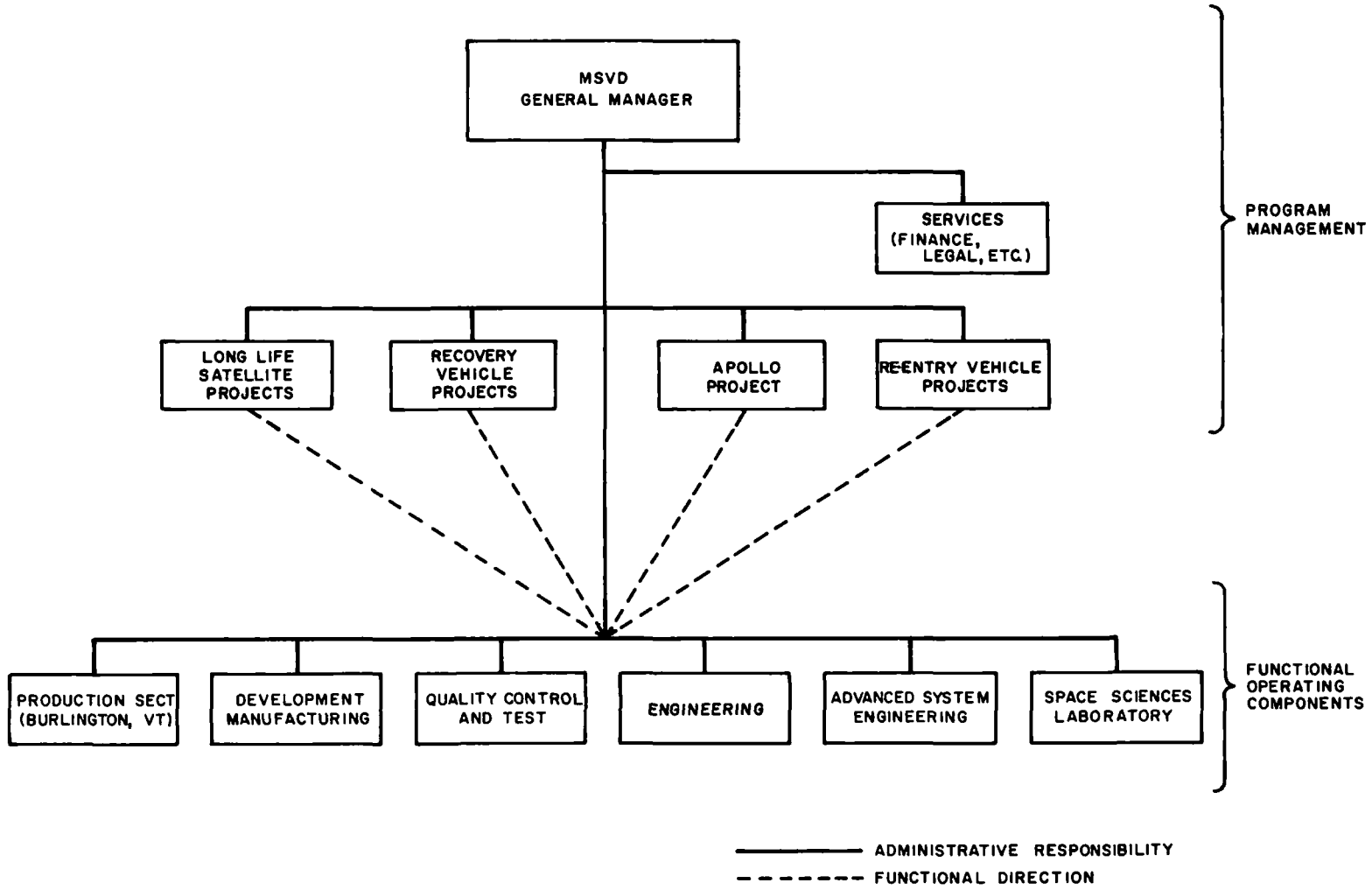

Figure B-3. Missile and Space Vehicle Department organization chart

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will be assigned to APOLLO to perform quality control engineering, vendor surveillance, inspection and test, material and process control, manufacturing in-process quality maintenance, bonded stock control, failure reporting and analysis, data processing and computation, and field support.

1.2 RELATED GENERAL ELECTRIC COMPANY-MISSILE AND SPACE VEHICLE DEPARTMENT EXPERIENCE

The total experience of the Missile and Space Vehicle Department, together with its predecessor Departments, spans sixteen years in rockets, missiles, and space vehicles. Figure B-4 shows the progression over this period, from early V-2 experiments, through ballistic re-entry vehicles, to satellites. Figure B-5 shows the MSVD progress over the past five years in space vehicles.

The Thor, Atlas and Thor/Able programs have demonstrated the Department's competence in a wide range of significant interrelated areas. In completing these programs, the Department was responsible for all phases from conception of initial ideas through flight results analyses. Specifically, these responsibilities were design, fabrication, reliability test programming, logistic problems of delivery and storage, launch pad checkout responsibility and analysis of actual flight data.

The Air Force ballistic missile re-entry vehicle program had a number of related development goals. To meet these goals, eighteen different re-entry vehicle models were included in the series. Many were short-term, limited-fund experimental devices. The terminal-stage vehicle for Able Phase One, for example, was delivered for flight test within forty-one days from inception. The most recent example is the completion and delivery, in eighteen months, of the high-performance, operational Mark 3 re-entry vehicle.

Other space-oriented work over the five-year period grew out of the re-entry vehicle program. On subcontract to Lockheed Aircraft Co., MSVD is providing

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SIXTEEN YEARS OF GENERAL ELECTRIC SPACE VEHICLE EXPERIENCE

1945 — 1961

- V-2 PROGRAM· 67 Ballistic Missiles reconstructed, tested and flown.
- BUMPER 8 Two-Stage rockets fired for new altitude, speed records.
- SANDY First large rocket missile fired from ship at sea.
- HERMES A-1· Radio command guided SSM.
- HERMES A-2 Large solid propellant rocket SSM (RV-A-10).
- HERMES A-3· Radio-inertially guided high performance SSM.
- HERMES B Supersonic ram-jet testing.
- HERMES C Long range semi-ballistic and glide studies.
- NACA/MSVD TESTS Three and five stage re-entry test vehicle flights.
- MARK 2 RE-ENTRY VEHICLE Heat Sink nose cone development, now operational THOR.
- MARK 3 RE-ENTRY VEHICLE· High performance ablating nose cone program for ATLAS
- DEVELOPMENT RE-ENTRY VEHICLES Rvx-1, Rvx-2, Rvx-2A, and MARK 3C-TP special test and recovery programs.
- SPACE LABORATORY Exploitation of nose cone flights in outer space, some with life support subsystems.
- DISCOVERER RECOVERABLE SATELLITE Recoverable life support satellite - only recovered U. S. satellite.
- ADVENT COMMUNICATION SATELLITE Long life satellite under design.
- NERV Space vehicle for measuring Van Allen radiation belts.
- SKYBOLT RE-ENTRY VEHICLE Air launched ballistic vehicle being designed.
- MARK 6 RE-ENTRY VEHICLE Ablating re-entry vehicle being designed for TITAN.
- NIMBUS System integration and testing, vehicle control subsystem design.
- SAMOS SATELLITE· Being designed.
- ORBITING ASTRONOMICAL OBSERVATORY· Control and stabilization system being designed

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Figure B-4. GE-MSVD space vehicle experience

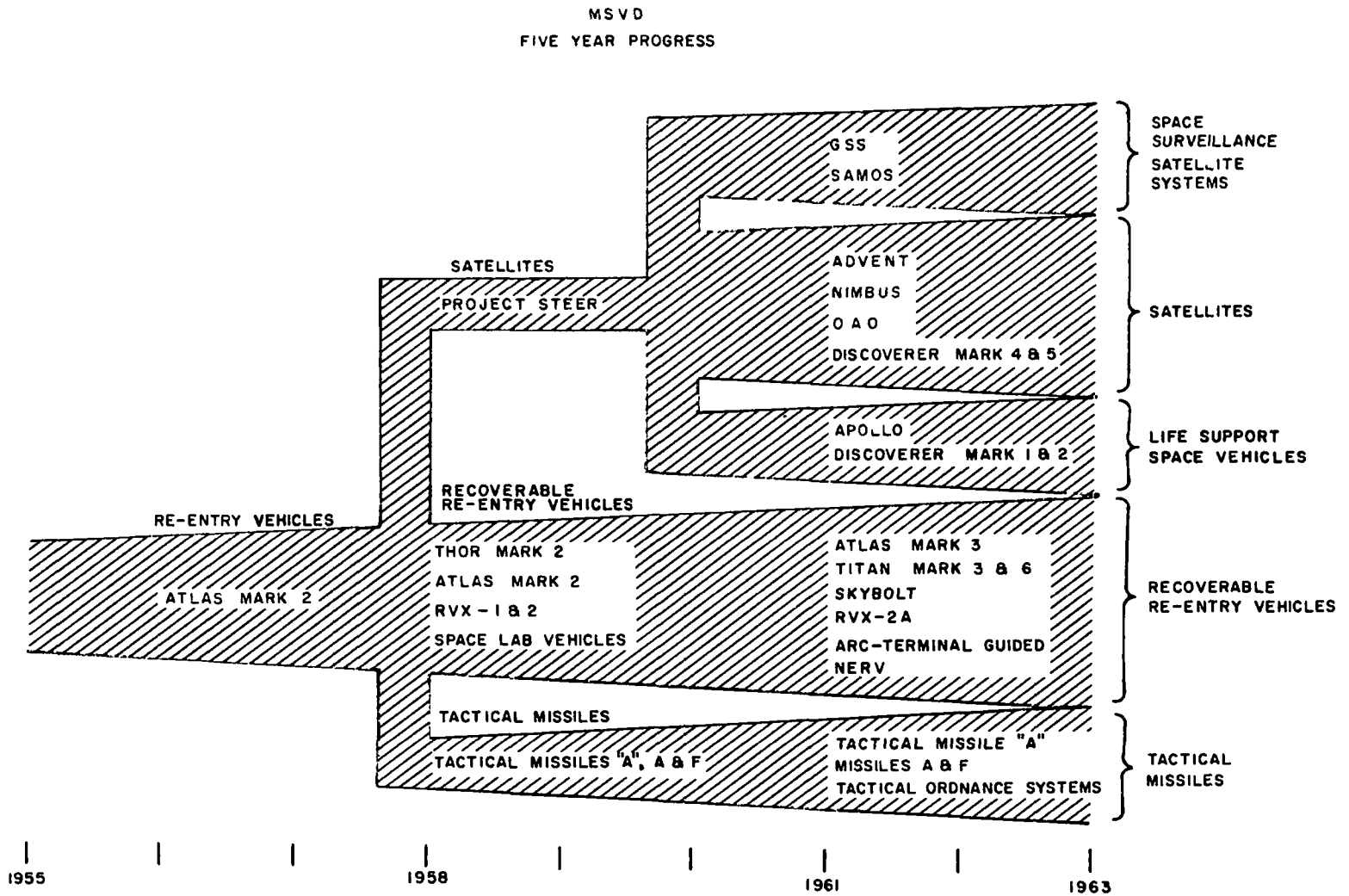

Figure B-5. MSVD progress in past five years

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Satellite Aeromedical Recovery Vehicles for the Discoverer satellite program. Using this configuration, the NERV (Nuclear Emulsion Recovery Vehicle) was built by MSVD and delivered to NASA for Van Allen radiation belt studies. Both the Discoverer and NERV vehicles have performed successfully in recent flights.

With AFBMD approval, scientific and hardware experiments were added to the payload of Mark 2 and RVX re-entry vehicle flights as shown in Figure B-5a. This concept, the Space Laboratory Program, is still operating in present MSVD re-entry vehicle programs. From the original program, the experiments resulted in flight-proven components, and demonstrated the possibility of early development of a stabilized satellite vehicle.

In addition to the above, MSVD is presently responsible for systems management, design, fabrication, test, and logistic support of the Advent, Samos, Mark 6 (TITAN), Skybolt, Nimbus and OAO programs which are in the design and early development phases.

MSVD has contributed a significant number of "space-firsts" in the five years. These space accomplishments are listed in Figure B-6.

The balance of this section describes specific hardware and discipline experience of MSVD which is directly applicable to APOLLO.

1.2.1 Space Vehicle System Design Experience

The following re-entry and space vehicle systems have been successfully designed, developed, manufactured and flight tested by MSVD.

1.2.1.1 MARK 2 RE-ENTRY VEHICLE

The Mark 2, Figure B-7, the first operational re-entry vehicle in the free world, was designed for use on both the Atlas and the Thor missiles. It employs the heat sink solution to re-entry heating, weighs 3500 pounds, and when used on Atlas,

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MARK 2, RVX-1, RVX-2 FLIGHTS ON THOR
THOR-ABLE AND ATLAS

EXPERIMENT	SPONSOR	FLIGHTS
IR HORIZON SENSORS	AFBMD/GE	2
SUNTRACKER	AFBMD/GE	1
MAGNETOMETERS	AFBMD/GE	5
TWO-AXIS STABILIZED VEHICLE	AFBMD/GE	2
THREE-AXIS STABILIZED VEHICLE	AFBMD/GE	5
SATELLITE ORBIT CONTROL	AFBMD/GE	3
VIBRATION AND NOISE MEAS	AFBMD/WADD	2
HIGH ALT. PHOTOGRAPHY	AFBMD/AFCRC/GE	8
MICROMETEORITES	AFCRC	14
VAN ALLEN BELT RADIATION	AFBMD/AFCRC/AEC	9
ELECTRIC FIELD	AFCRC	3
ION DENSITY	AFCRC	2
ELECTRON DENSITY	AFCRC	2
ATMOSPHERIC DENSITY	AFCRC	2
RADIO PROPAGATION	AFBMD/GE/AFCRC	5
RE-ENTRY SHOCK	AFCRC	3
PARTICLE DISPERSION	WADD	1
SOLAR POWER CELL	GE	1

RVX-2A FLIGHT ON ATLAS

EXPERIMENT	SPONSOR
COLOR AND B&W CAMERAS	GE/CRC
BIO-SPECIMENS (3 MICE)	AFSAM
ULTRA VIOLET BACKGROUND	WADD
RADIATION MEAS. OF LOWER VAN ALLEN BELT	LRL
GROSS RADIATION MEAS. INSIDE VEHICLE	LRL
COSMIC RADIATION	CRC
PROTON MEASUREMENTS	LASL
RADIATION MEAS. INSIDE VEHICLE	LASL
DOSIMETER	AFSWC
EMULSION PACK	NASA
HOT GAS SPECTROGRAPH	GE
MHD PLASMA CHARACTERISTICS	STL
INTEGRATING ACCELEROMETER	GE
PASSIVE TRANSPIRATION COOLING	GE
REGENERATIVE FUEL CELL	GE
S-BAND REFLECTIVITY	GE
X-BAND REFLECTIVITY	GE
COSMIC NOISE	GE

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Figure B-5a. Space Laboratory Program

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ABLATION THEORY ADAPTED TO IST RIGOROUS THEORETICAL SOLUTION TO ICBM ABLATION RE-ENTRY DESIGN	JULY 57
IST OPERATIONAL TYPE HEAT-SINK IRBM RE-ENTRY (MARK 2)	JUNE 58
IST RECOVERY OF PAYLOAD FROM OUTER SPACE (MARK 2 DATA CAPSULE)	JUNE 58
IST SUCCESSFUL ABLATION RE-ENTRY OVER ICBM RANGE ("ABLE")	JULY 58
IST OPERATIONAL TYPE HEAT-SINK ICBM RE-ENTRY (MARK 2)	SEPT 58
IST INFRARED MEASUREMENT OF EARTH-SPACE INTERFACE (MARK 2 SPACE LABORATORY)	DEC 58
MARK 2 OPERATIONAL ON THOR	DEC 58
IST MEASUREMENT OF EARTH'S MAGNETIC FLUX FROM OUTER SPACE (MARK 2 SPACE LABORATORY)	MARCH 59
IST POSSIBLE RETURN OF A PAYLOAD FROM OUTER SPACE ORBIT (DISCOVERER II)	APRIL 59
IST RECOVERY OF COMPLETE RE-ENTRY VEHICLE OVER ICBM RANGE (RVX-1)	APRIL 59
IST MOTION PICTURES OF EARTH FROM TRAVELING SPACE VEHICLES AT ALTITUDES FROM 280 MILES TO 800 MILES (MARK 2 SPACE LABORATORY)	MAY 59
IST 3-AXIS (INDIVIDUALLY) STABILIZED SPACE PLATFORM (MARK 2 SPACE LABORATORY)	JULY 59
LARGEST VEHICLE IN WORLD EVER RECOVERED FROM SPACE AT THAT DATE (RVX-2)	JULY 59
MARK 2 OPERATIONAL ON ATLAS	SEPT 59
IST OPERATIONAL TYPE 2ND GENERATION ABLATION ICBM RE-ENTRY (MARK 3)	OCT 59
MARK 3 OPERATIONAL ON ATLAS	APRIL 60
LONGEST RE-ENTRY VEHICLE FLIGHT IN THE WORLD (9,000 MILES, MARK 3)	MAY 60
IST SPACE VEHICLE IN THE WORLD TO BE RECOVERED FROM SATELLITE ORBIT (DISCOVERER XIII)	AUG 60
IST MID-AIR RECOVERY OF A SPACE VEHICLE RETURNING FROM SATELLITE ORBIT (DISCOVERER XIV)	AUG 60
HIGHEST ALTITUDE ACHIEVED BY A SUBSEQUENTLY RECOVERED RE-ENTRY-RECOVERY VEHICLE (NERV)	SEPT 60
IST COLOR MOTION PICTURES OF EARTH FROM A TRAVELING SPACE VEHICLE FROM ALTITUDES UP TO 700 MILES (RVX-2A SPACE LABORATORY	OCT 60

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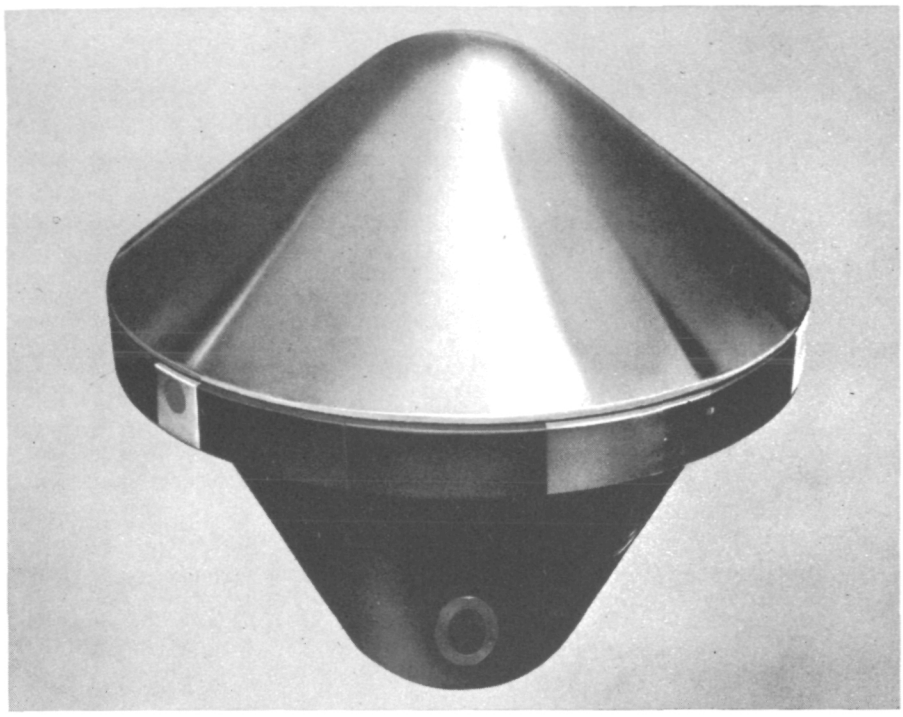
Figure B-6. MSVD space accomplishments



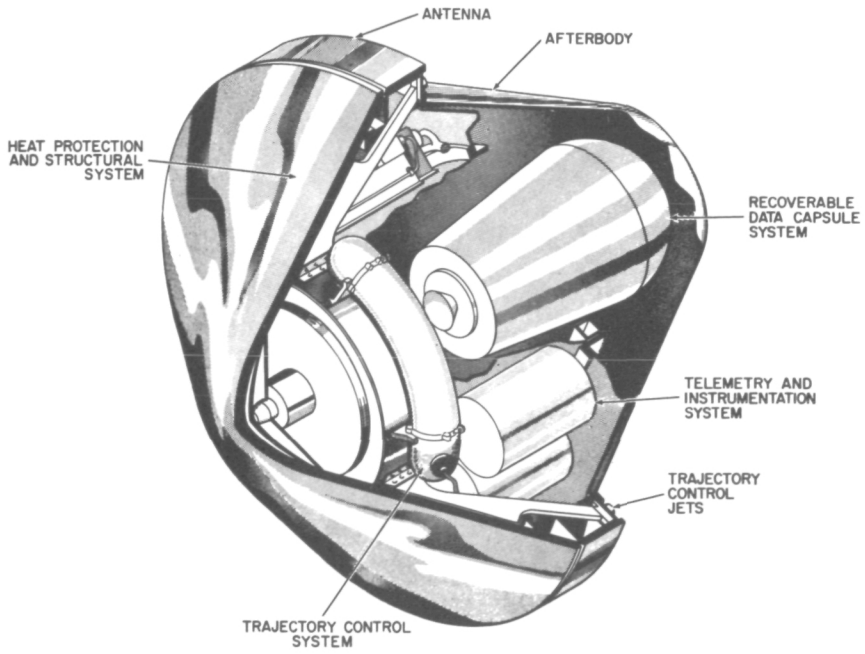


Figure B-7. Mark 2 heat-sink-type re-entry vehicle

has flown at ranges up to 5500 nmi. The blunt conical configuration affords relatively low re-entry velocities (W/C_DA of 125) which, together with trajectory control for damping the rate of angle-of-attack oscillations, keep the re-entry heat input within the limits of the heat sink design. This vehicle has completed extensive flight test evaluation, during which it performed successfully on all flights in which the booster allowed re-entry vehicle separation. The R&D version of the Mark 2 design included a recoverable data capsule ejected after re-entry. A tape recorder within the capsule recorded telemetry information during the ionic "blackout" of communications that occur during re-entry. During the R&D flight test program, the Mark 2 re-entry vehicle carried a large number of independent space experiments in "piggyback" fashion. Thus, it served as a flying space laboratory, in addition to performing its primary flight objective — the gathering of maximum data from each flight. These successful piggy-back experiments include:

- Two-axis infrared horizon stabilization
- Three-axis stabilization using sun tracker and/or magnetomer to achieve third reference point.
- Motion pictures of earth from altitudes ranging from 280 to 800 miles.

The Mark 2 re-entry vehicle is now operational on both the Atlas ICBM and the Thor IRBM.

1.2.1.2 THOR-ABLE PHASE 0 RE-ENTRY/RECOVERY VEHICLE

Able Phase 0, Figure B-8, demonstrated the successful re-entry of a low W/C_DA, ablation type re-entry vehicle at ICBM-range velocities, and thus proved the feasibility of an operational ablation type ICBM re-entry vehicle. This program was started in December, 1957, and first delivery of the re-entry vehicle was made to the USAF in only 41 days.

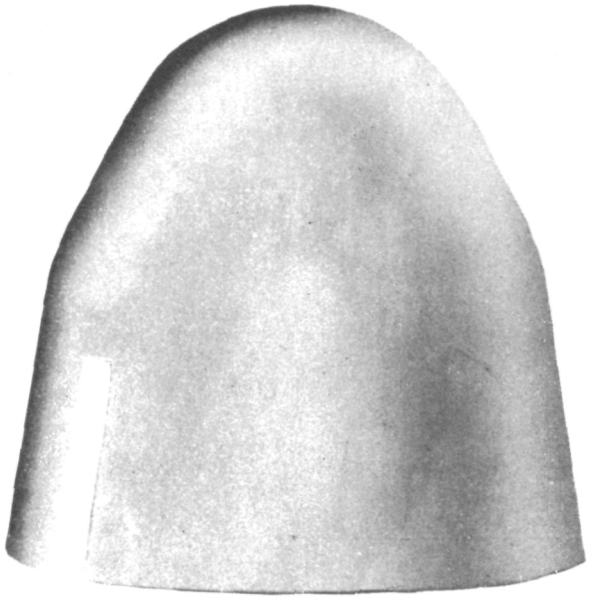


Figure B-8. Able Phase 0 experimental ablation-type re-entry vehicle

The Able Phase 0 Re-entry Vehicle is a sphere-cone flare configuration having an over-all length of 34 inches and a base diameter of 38 inches. The total weight of the vehicle is 625 pounds. It employs melamine glass and phenolic refrasil as ablation materials. The primary means of acquiring flight test data was through a telemetry system, providing the real time transmission of data continuously through flight. Ablation sensors were included to instrument the effects of re-entry.

Of three flights, there were two chances for re-entry. On these two flights, both during July, 1958, the re-entry vehicle travelled the full ICBM range and performed successfully. Although a recovery system was incorporated in Able Phase 0, no recovery of the vehicle was accomplished.

1.2.1.3 RVX-1 RE-ENTRY/RECOVERY VEHICLE

The RVX-1 Re-entry/Recovery Vehicle, Figure B-9, was the first vehicle ever recovered after flying the full ICBM range. It established the effective heat of ablation, the char depth, and the insulating properties of the materials tested, thus establishing the design parameters for second-generation ablation re-entry vehicles.

The RVX-1 is a sphere-cone-cylinder-flare configuration, having a length of 67 inches, a cylinder diameter of 15 inches, a flare diameter of 27 inches, and weighing 625 pounds. The Missile and Space Vehicle Department supplied the basic vehicles, including structures, instrumentation, and recovery packages, while both General Electric and Avco supplied the ablation materials to be flight tested.

In addition to a complete telemetry system, the vehicle contained a recovery and location package to permit recovery of the entire vehicle. Out of six flights made on the Thor-Able missiles, there were four chances for re-entry and recovery. All four vehicles successfully re-entered and two were successfully recovered.

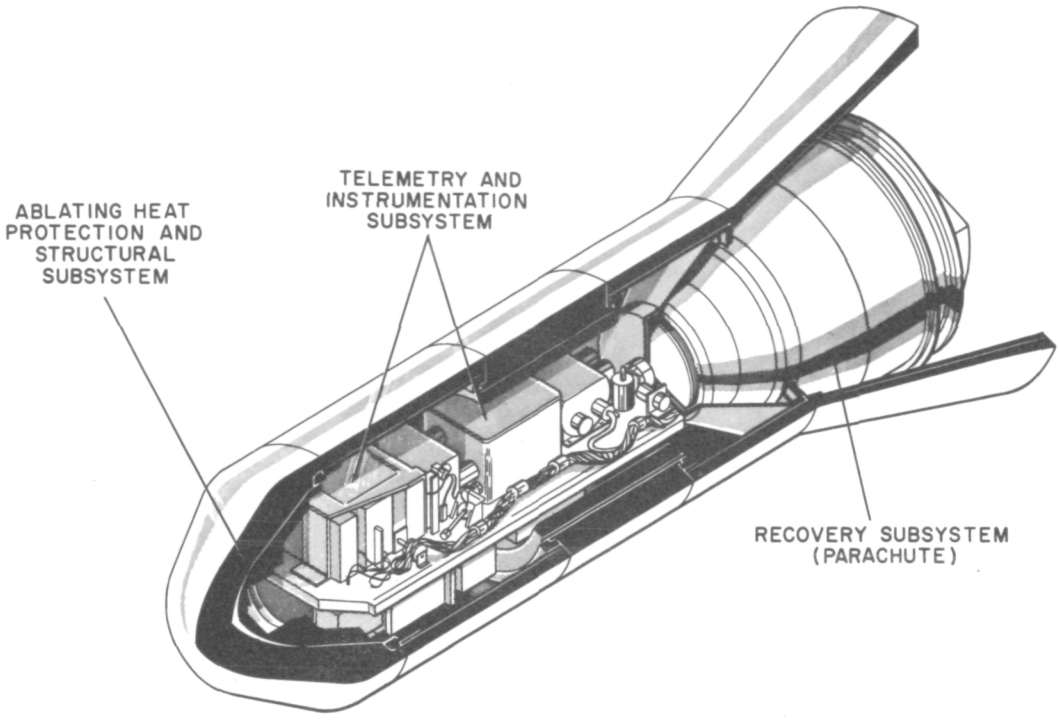


Figure B-9. RVX-1 experimental ablation-type re-entry vehicle

1.2.1.4 RVX-2 RE-ENTRY/RECOVERY VEHICLE

The 2500-pound, 12-foot long RVX-2 vehicle, similar to the vehicle proposed for the Samos E-6 program, has been successfully flight tested and recovered. (See Figure B-10.) The RVX-2 is the largest vehicle with the largest payload ever to be recovered from space in the Free World. Fired in July, 1959, on an Atlas missile, the RVX-2 covered the full ICBM range.

A sphere-cone configuration, the RVX-2 is 12 feet long, 5 feet in base diameter, and weighs 2500 pounds. It utilizes phenolic nylon as the ablation heat protection material.

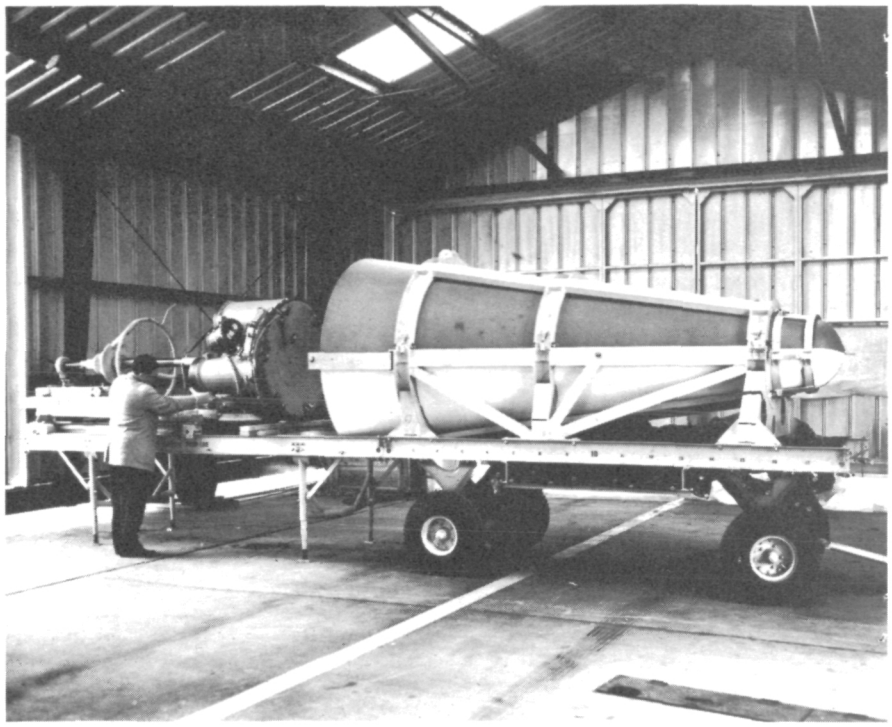
The RVX-2A is a follow-on to the RVX-2 program. The primary purpose of these flights is materials evaluation on a full-scale re-entry vehicle. In addition to the primary objective, space laboratory experiments will be carried in the RVX-2A to utilize "over-the-top" trajectory time to make each flight yield a maximum amount of data on space environmental conditions and also to flight test advanced subsystems for space vehicles. Figure B-11 lists the Space Laboratory Experiments installed in the RVX-2A vehicle number 423.

An RVS-2B Program provides for an inertially guided, fin-controlled vehicle — basically the RVX-2 containing an aerodynamic-maneuver capability as a means to decrease dispersion. Related studies in support of this concept are currently under way at MSVD.

1.2.1.5 MARK 3 RE-ENTRY VEHICLE

The Mark 3 re-entry vehicle, Figure B-12, a second-generation design, is now operational on Atlas missiles. The Mark 3, designed for use on either the Atlas or Titan, was first flight tested in October, 1959, with operational deliveries initiated in December, 1959.

The Mark 3 re-entry vehicle is a sphere-cone-cylinder-flare configuration with ablation heat protection and an integrated warhead/re-entry vehicle structure.



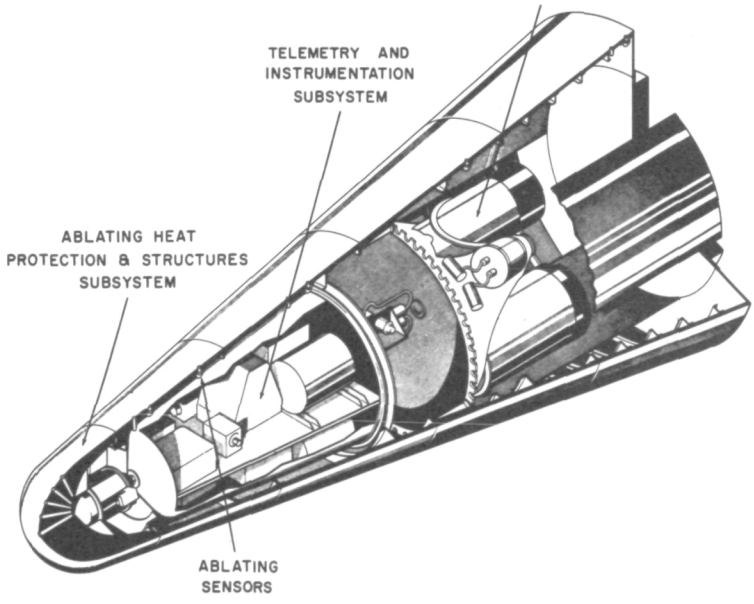
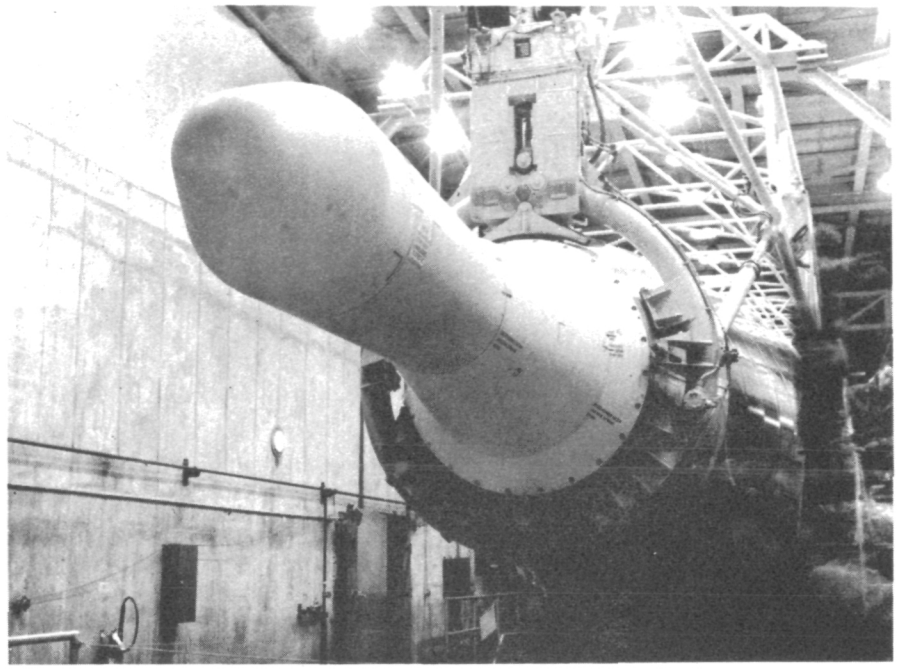


Figure B-10. RVX-2 experimental ablation-type re-entry vehicle

SPONSOR	EXPERIMENT	PURPOSE
GE/CRC	CAMERAS	• MEAS. REFLECTANCE (ALBEDO); PHOTOGRAPH STAR FIELDS AND LAND • MASSES AT NIGHT AND CLOUD COVER
AFSAM	BIO-SPECIMEN	• TO EVALUATE THE EFFECTS OF RADIATION AND EXTENDED PERIODS OF ZERO G ON MAMMALIAN LIFE (3 MICE)
WADD	ULTRA VIOLET BACKGROUND	• MEASURE ALBEDO OF EARTH'S ATMOSPHERE AS FUNCTION OF ALTITUDE
LRL	RADIATION	• OBTAIN MEASUREMENTS OF FLUX AND ENERGY DIST. OF PROTONS AND ELECTRONS IN LOWER VAN ALLEN BELT
LRL	RADIATION	• MEASURE GROSS INTERNAL ENVIRONMENT OF VEHICLE
CRC	COSMIC RAY	• HIGH RISK PACKAGE MEASUREMENTS OF TRAPPED AND PRIMARY COSMIC RADIATION
LASL	PROTON MEAS.	• WIDE RANGE PARTICLE ENERGY MEASUREMENTS
LASL	RADIATION	• VEHICLE INTERNAL RADIATION ENVIRONMENT
AFSWC	DOSIMETER	• MAKE TISSUE EQUIVALENT DOSAGE MEASUREMENTS IN INTERIOR OF RE-ENTRY VEHICLE
NASA	EMULSION PACKAGE	• MEASURE INTERNAL RADIATION ENVIRONMENT IN VICINITY OF SKIN OF RE-ENTRY VEHICLE
GE	HOT GAS SPECTROGRAPH	• 3 CHANNEL MEASUREMENTS OF RE-ENTRY HOT GAS RADIATION BETWEEN 4000 AND 7500 ANGSTROMS
STL	MHD	• MEASURE FIELD CHARACTERISTICS OF PLASMA DURING RE-ENTRY, SPECIFICALLY CONDUCTIVITY
GE	INTEGRATING ACCELEROMETER	• EVALUATE PERFORMANCE OF INERTIAL VELOCIMETER
GE	PASSIVE TRANSPIRATION COOLING	• EVALUATE MEANS OF CONTROL SURFACE DEVELOPMENT
GE	FUEL CELL	• EVALUATION OF REGENERATIVE FUEL CELL IN ZERO G ENVIRONMENT
WADD	S-BAND REFLECTIVITY	• MEASURE VSWR AT 3200 MCS
GE	X-BAND PROPAGATION	• MEASURE VSWR IN THE X-BAND REGION, 10,000 MCS
GE	COSMIC NOISE	• PASSIVE X-BAND RECEIVER

Figure B-11. Space laboratory experiments on RVX-2A/423



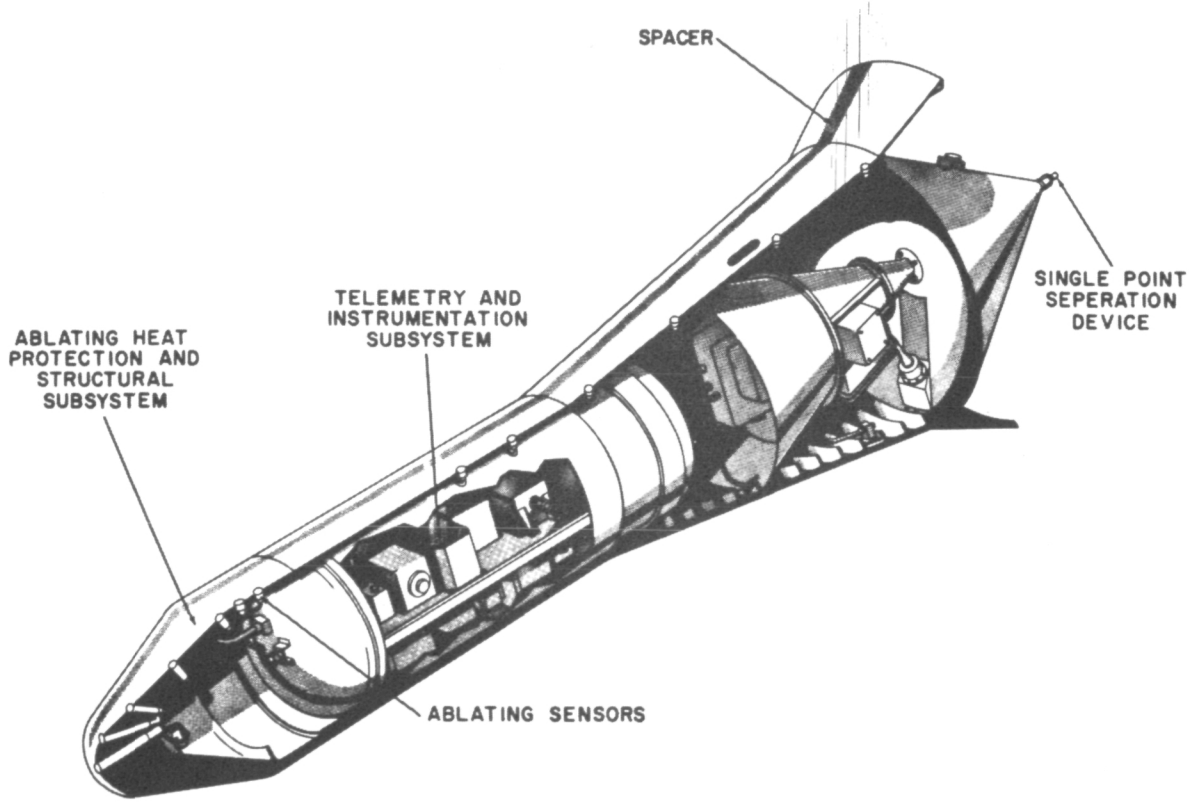


Figure B-12. Mark 3, ablation-type re-entry vehicle

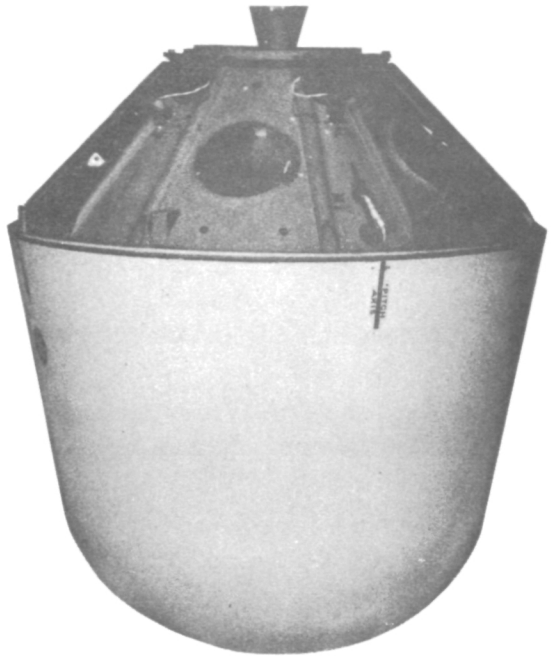
The Mark 3, a high W/C_DA vehicle (1300), compared to the first generation Mark 2 re-entry vehicle reduced the total weight by about 1300 pounds, decreased the intercept time from 120 to 50 seconds, and reduced the dispersion attributable to re-entry from 1.0 to 0.2 nmi. To date, the Mark 3 re-entry vehicle has been successfully flight tested 18 times.

1.2.1.6 DISCOVERER ORBITAL RE-ENTRY/RECOVERY VEHICLES

The Discoverer satellite recovery vehicle, designed, developed and fabricated by MSVD, was the first space vehicle ever recovered from orbit. Figure B-13 shows a cut-away view of the satellite recovery vehicle.

The Discoverer satellite re-entry vehicle is 33 inches in diameter, 40 inches long, and weighs about 300 pounds. After separation from the Agena, the satellite recovery vehicle is de-orbited by a retro-rocket; stabilization occurs through its own control system. After retro burnout, the vehicle is on a ballistic trajectory. Drag and heating effects become severe at about 350,000 feet, causing the heat shield temperature to rise to about 4000 F. Thin gold plating on the inside of the shield helps protect the payload from the relatively long exposure to aerodynamic heating. Deceleration occurs with a maximum force of 10-15 G's. Between ejection from orbit and recovery, the vehicle covers a distance of about 2000 nmi. After re-entry, a parachute attached to the recoverable capsule opens at 50,000 - 55,000 feet altitude. The capsule can then be retrieved either by air-snatch or sea recovery. Recovery aids such as a radio beacon and signal lights operate throughout the recovery phase.

DISCOVERER XIII and XIV were successfully recovered after orbital flight and re-entry to the atmosphere in August 1960. Discoverer XV was located after flight, but heavy seas prevented recovery. Discoverers XVII and XVIII were successfully caught in mid-air after orbital flight. Of particular interest to APOLLO is the fact that the most recent Discoverer flights carried scientific payloads and experiments integrated by MSVD. Several of the vehicles launched



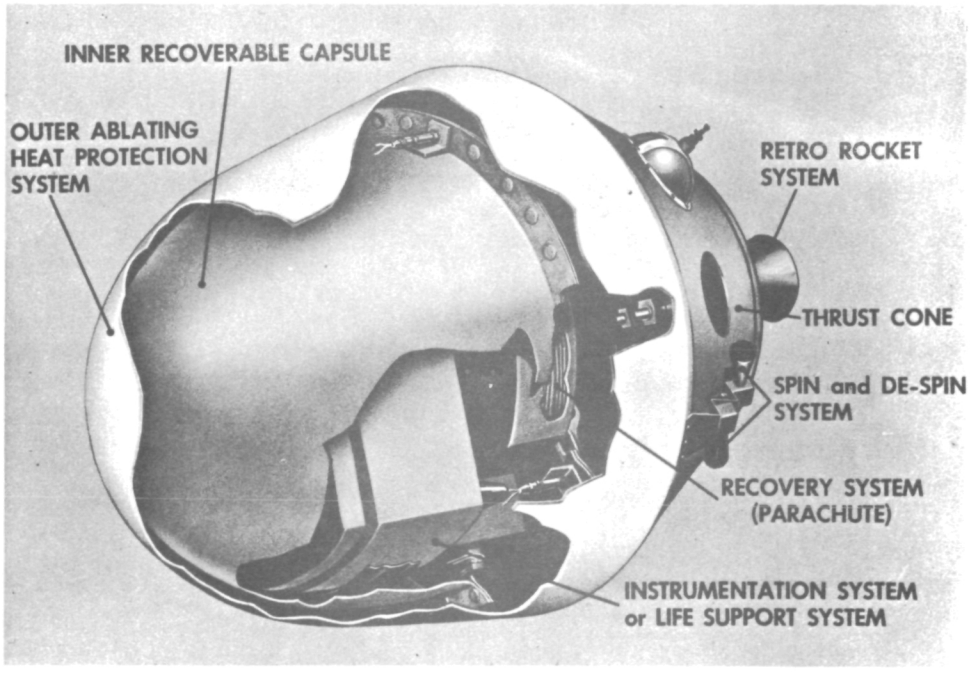


Figure B-13. Discoverer orbital re-entry/recovery vehicle

in future DISCOVERER flights will carry biomedical subjects such as rodents and primates.

The experience gained and the capabilities developed on DISCOVERER are uniquely applicable to the APOLLO Program.

1.2.1.7 NUCLEAR EMULSION RECOVERY VEHICLE

The General Electric-designed and developed the NASA Nuclear Emulsion Recovery Vehicle (NERV), a unique space radiation measurement vehicle, has the distinction of being the object recovered from the highest altitude.

The re-entry vehicle, Figure B-14, weighs 83.6 pounds and has a diameter of 19 inches and a length of almost 17 inches. The NERV vehicle was first launched and recovered on September 19, 1960. It utilizes an ablation heat shield and was designed for measuring radiation intensities at various altitudes, returning these measurements in physical form back to earth for study. The measurements are obtained by telescoping a cylindrical disk from the shuttered forward portion of the vehicle and exposing a nuclear emulsion package which is then retracted before re-entry. The recovered vehicle provided a visual record of the characteristics of ionization particles in the 10 to 150-Mev range above the atmosphere by allowing the particles to cut a trace on the nuclear emulsion. Exposure to the radiation field began at altitudes of 200 miles during the ascent and continued through an apogee of over 1200 miles.

The NERV II Program, recently initiated, will achieve additional flights with other experimental objectives. All NERV vehicles have a complete recovery system, including parachute and location aids.

1.2.1.8 GAM 87A SKYBOLT RE-ENTRY VEHICLE

The re-entry vehicle and associated ground support equipment for the Skybolt Weapon System are also being developed by the Missile and Space Vehicle Department.

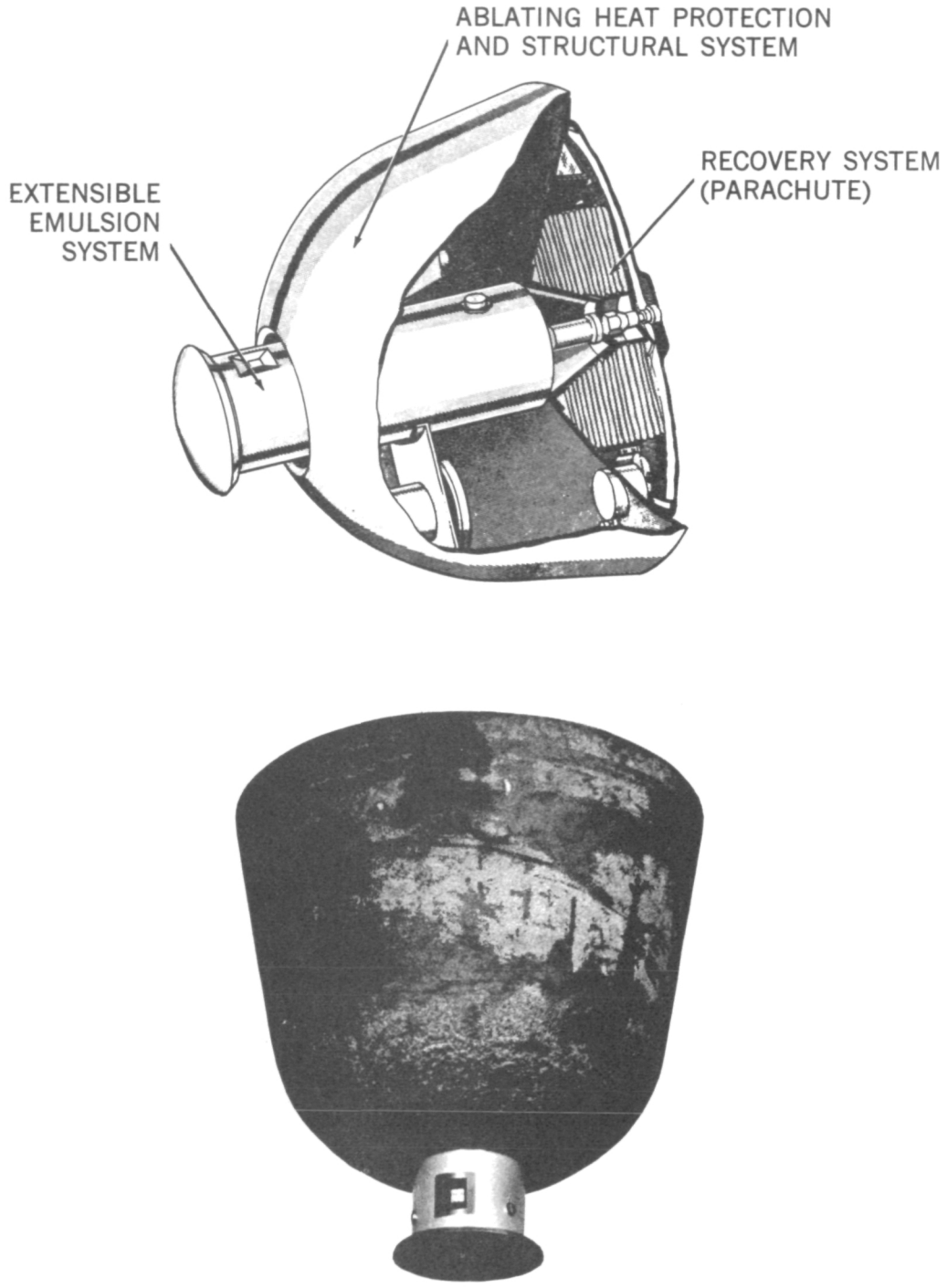


Figure B-14. Nuclear emulsion recovery vehicle (NERV)

The Skybolt re-entry vehicle program involves unique design and development challenges associated with an air-launched ballistic missile. The re-entry vehicle must be capable of withstanding long-term exposure to the environments of aircraft flight as well as exposure on the ground while attached to the aircraft. The vehicle will be subjected to such phenomena as acoustic noise, temperature cycling, vibration, rain and hail. Exit heating effects; i. e., the heating effects encountered when the missile is fired while travelling at high speeds aboard the aircraft at altitudes still within the sensible atmosphere, impose additional design requirements.

The re-entry vehicle is a sphere-cone-cylinder-flare configuration and employs a phenolic refrasil and phenolic impregnated nylon as the ablation heat protection materials.

The Skybolt re-entry vehicle has a cylinder diameter of 19 inches, flare diameter of 36 inches, length of 122 inches, and weighs about 300 pounds less warhead. The Skybolt re-entry vehicle is designed for minimum weight and complexity and maximum reliability. See Figure B-15.

1.2.1.9 MARK 6 RE-ENTRY VEHICLE

MSVD is well into the program of developing a third-generation re-entry vehicle, the Mark 6, for Titan II. The Mark 6 vehicle has a high payload-to-gross-weight ratio and can deliver a warhead with a significantly higher yield than that of the Mark 2 and Mark 3 re-entry vehicles.

The Mark 6 has a conical configuration with a spherical nose. It has an over-all length of 129.8 inches, an aft diameter of 71.0 inches, and a 17.5-inch radius nose. The vehicle weighs approximately 7200 pounds. With the addition of the spacer section, which adapts the re-entry vehicle for mating to the Titan II, the diameter increases to 84.0 inches, the length to 151 inches, and the weight to 7350 pounds. The ballistic parameter (W/C_DA) of the Mark 6 is approximately 600 pounds per square foot.

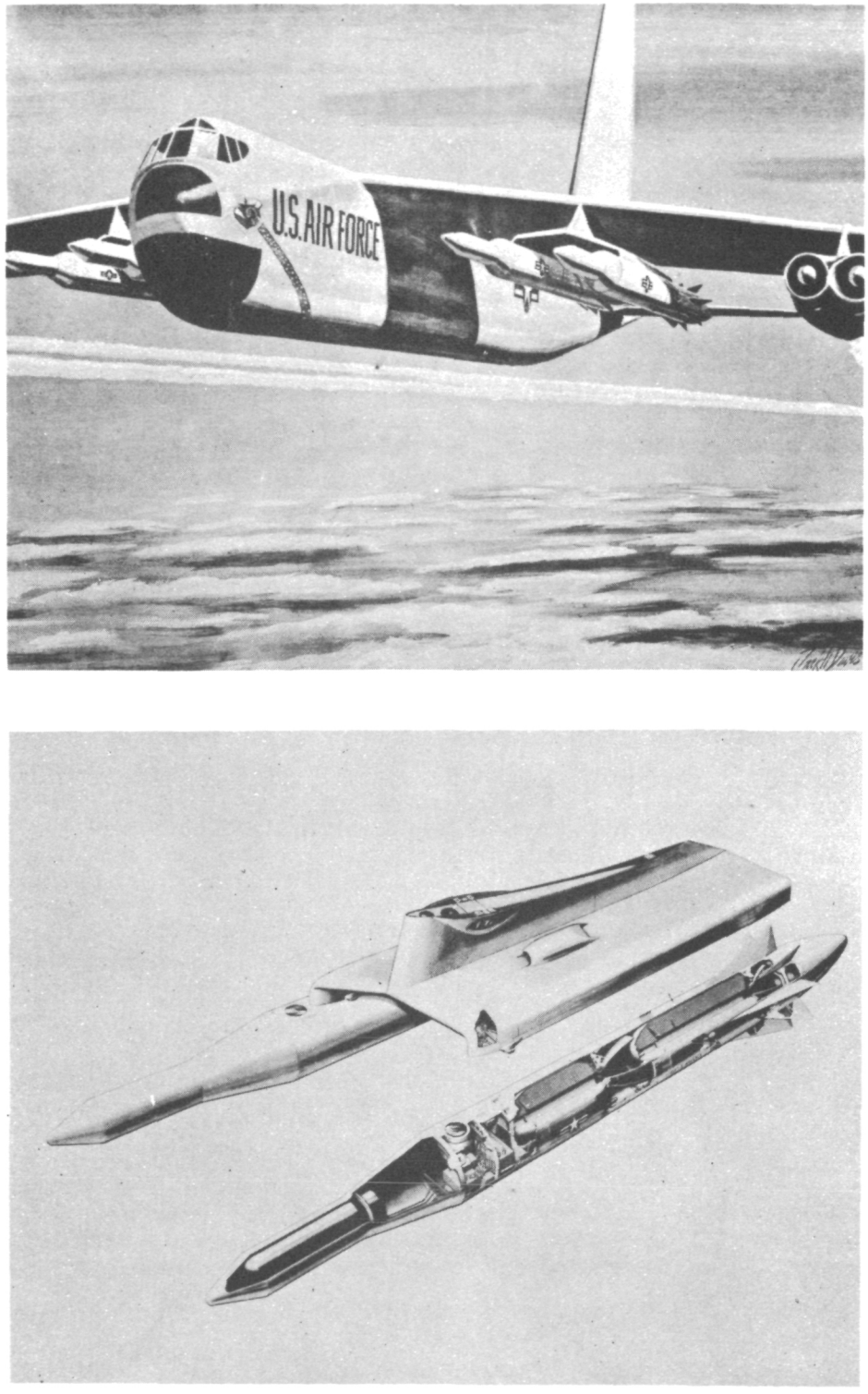


Figure B-15. Skybolt re-entry vehicle

Advanced phenolic plastic materials, developed by the General Electric Company, are used for the ablation heat protection. The nose section utilizes G-E Series 100 material, the aft section G-E Series 500 material. Both materials are castable and both are based on epoxy type resins combined with suitable additives, fillers, curing agents, and catalysts resulting in light, efficient, easily fabricated shielding materials.

1.2.1.10 ADVENT COMMUNICATION SATELLITE

ADVENT, Figure B-15a, the nation's first long-life communication satellite vehicle, is being designed and built by MSVD for the Department of Defense. These space satellites will orbit around the equator twenty-two thousand miles above the earth, acting as radio relay stations for the transmission of instantaneous radio communications. They are the first vehicles to use an active temperature control system, and have a long-life requirement of one year.

This system will be capable of filling the need for communications of high reliability, security, and large capacity under conditions of natural or man-made interference. Later applications for such communication satellites could include transmission of teletype, radio, and television broadcasts. MSVD responsibility in this program is the final stage vehicle, including active temperature control, vehicle structure, environment control, attitude control, including station keeping, airborne tracking, telemetry and command equipment, electric power supply, final stage propulsion, ground support equipment, integration of the microwave communications repeater, and integration and test of antennas.

The first ADVENT flights will be of orbital test vehicles at lower altitudes of 6000 miles. Their purpose is to verify ground studies and space simulation testing prior to building final flight spacecraft. These "OTV's" will be identical to the operational flight hardware except as modified for the lower orbit. Based on booster availability, the first ADVENT OTV flight is scheduled for early 1962.

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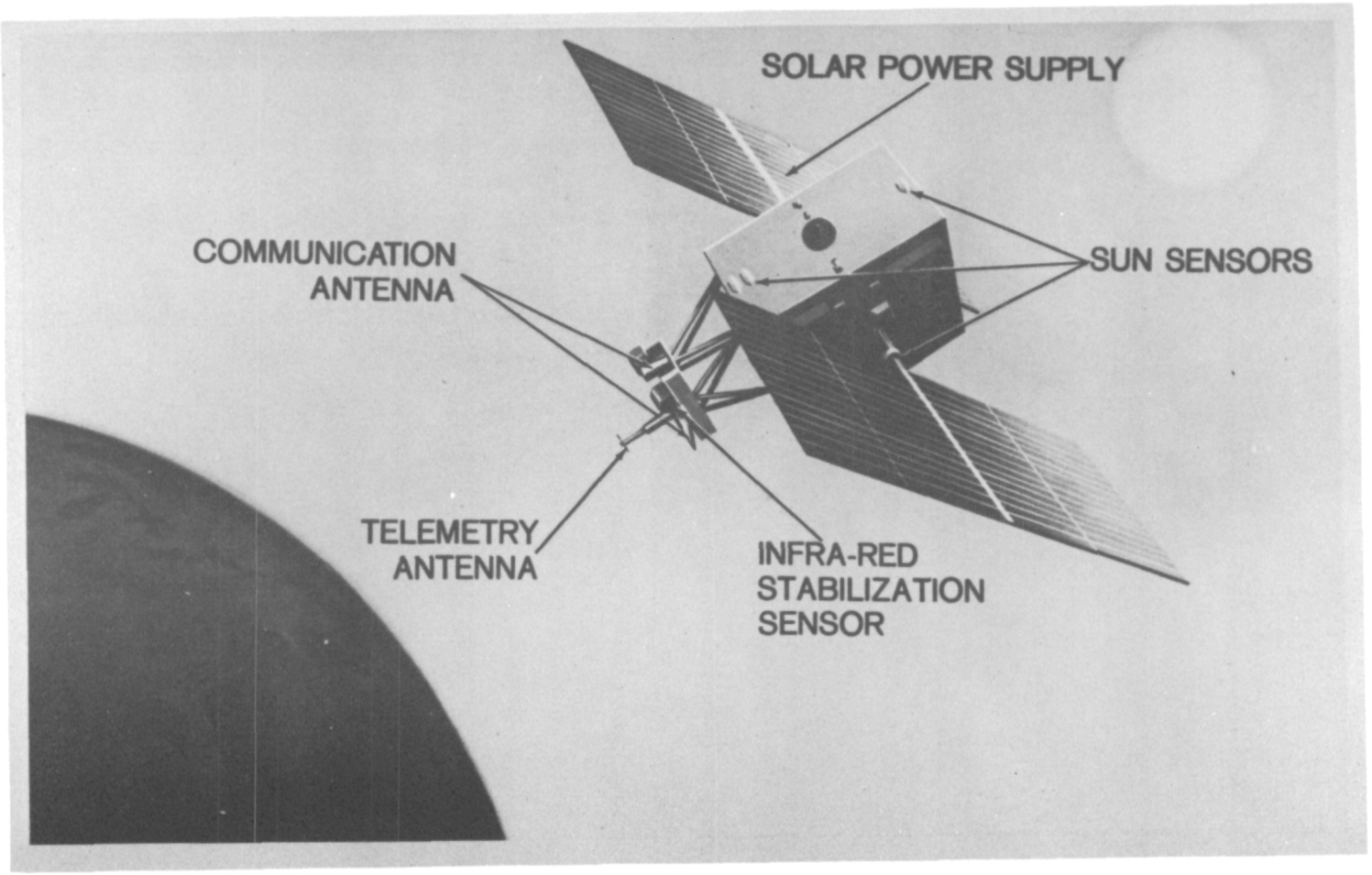

Figure B-15a. Advent Communication Satellite

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The results of these initial OTV flights, as well as the long-life parts data and procedures being evolved and put into use at MSVD offer a wealth of significant data and insight to APOLLO.

1.2.1.11 NIMBUS SPACE CRAFT

Under contract with NASA, MSVD is presently designing the control subsystem for the Nimbus space vehicle, and is responsible for the integration and testing of the entire Nimbus space craft. The vehicle is shown in Figure B-15b.

1.2.2 Missile and Space Vehicle Department Space Science Laboratory Experience

The Missile and Space Vehicle Department's Space Sciences Laboratory, located in Philadelphia, is the center at General Electric for Missile and Space Technology research and development.

Here, where the first comprehensive ablation theory for re-entry vehicle design was developed, a skilled Laboratory staff is pursuing a number of important space research programs, including studies of satellites and glide vehicles, space mechanics, plasma physics, impact phenomena, life support and materials problems. To conduct the inter-related research activities of all these programs, the Laboratory aligns its research efforts in five major groups that include: advanced aerodynamics, aerophysics, space mechanics, materials studies and special projects. In these groups, activities range from research and creative conception to scientific proof of feasibility. The following areas are applicable to APOLLO.

1.2.2.1 MATERIALS RESEARCH AND DEVELOPMENT

General Electric's Space Sciences Laboratory has pioneered in the research and development of materials designed to withstand the environments of space and re-entry. In fact, all vehicles recovered from earth orbit to date and an overwhelming number of all the ballistic re-entry vehicles launched and recovered have been built by the General Electric Company utilizing materials developed by the Space Sciences Laboratory. A few of the current space materials programs underway are:

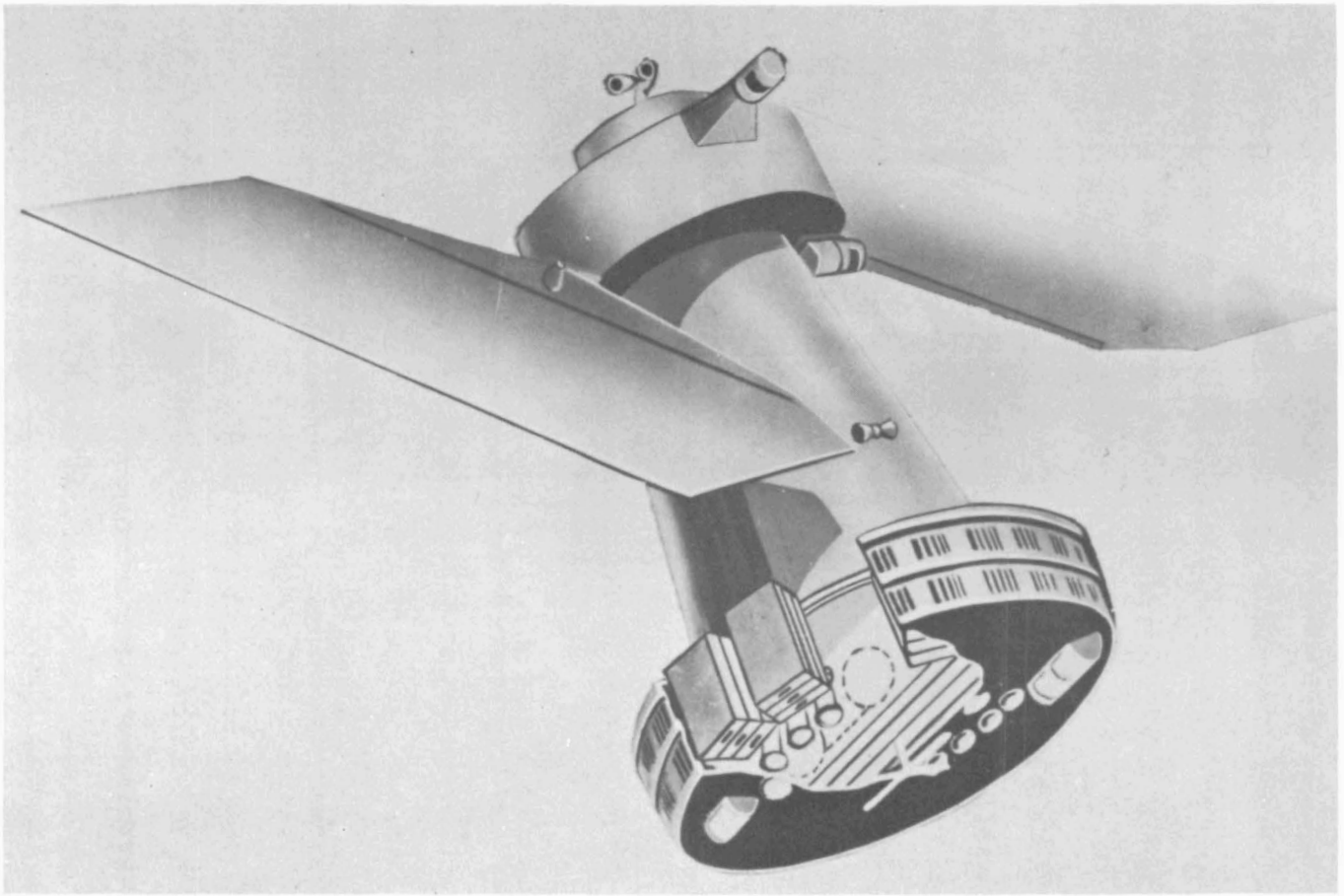

Figure B-15b. Nimbus Meteorological Satellite

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1.2.2.1.1 Whiskers

Laboratory scientists are developing techniques for growing high-strength crystal whiskers for use as reinforcing material in ultra-strong, light-weight, plastic materials. The work includes studies of factors affecting whisker growth and production, evaluation of composite fabrication techniques, and evaluation of the composites. Composites using aluminum oxide whiskers are expected to be three or four times stronger at white heat than any high-strength alloy.

1.2.2.1.2 Pyrolytic Graphite and Alloys

Space Sciences Laboratory personnel, working with General Electric's Research Laboratory, have perfected fabrication processes for pyrolytic graphite. . . a highly heat-resistant material with many possible applications in missile nose-cone heat shields, rocket-engine nozzles, and the steering vanes on missiles. It offers heat protection under long-time flight conditions that would produce gas temperatures of about 15,500 degrees F and surface temperatures of about 4,500 degrees R conditions beyond the endurance of virtually any other known material. Progress continues in this area as Laboratory scientists work with the development of pyrolytic alloys.

1.2.2.1.3 Foamed Metals and Ceramics

In recent years there have been many attempts to produce foamed metals and ceramics. At SSL, special emphasis is being placed on the development of such materials for use in re-entry and space vehicles. For example, preliminary research has established the feasibility of preparing foamed metals such as nickel, copper, aluminum, and magnesium. In addition, it appears possible to adapt the process for making foams of refractory materials such as hafnium carbide, tantalum carbide, hafnium oxide, and perhaps graphite.

1.2.2.1.4 Ablating Plastics

The "century series" of castable plastics developed by SSL have proved to be excellent ablating-type heat shields. These plastics afford heat protection by "planned destruction" — for example, plastic nose cones burn and vaporize from the surface inward, producing a cooling sheath of gases and a porous char which surrounds and protects the body of the re-entry vehicle. Made from low-pressure moldable resins (such as epoxies and polyesters), they are used in their clear form or modified to offer a wide range of physical and mechanical properties depending upon the specific need.

1.2.2.2 SPACE STRUCTURES

The study of structures is vital to continued progress in satellite and manned space vehicle development. At the Space Sciences Laboratory, scientists are investigating many types of structures for the military, government agencies and for other members of the space industry team.

For example, utilizing the Laboratory's advanced 30-inch shock tunnel, SSL personnel have conducted a comprehensive study program to determine high Mach number (above Mach 15) aerodynamic coefficients, surface pressure distributions, and surface heat transfer rate distributions on a semi-ballistic lifting, re-entry vehicle.

Laboratory scientists are also interested in exploring the possibilities of new configurations and new materials for space structures. The use of intersecting spheres in a circle in place of a toroid for a pressurized space vehicle is under consideration. Stress problems are simplified, the spheres provide natural compartmentation with bulkheads at the intersections, and weight savings may approach 20 percent. Multi-wall construction to protect against meteoroid penetration is being investigated. In the materials area, the use of hollow glass fibers may provide basic strength for lightweight glide vehicles.

Investigations of buckling upon impact have revealed definitive patterns in shell structures that may prove of major importance in design. A conical shell impacted axially demonstrates an inverse relationship between extensional buckle wavelength and impact velocity. Proper design may enable payloads to be landed without exceeding tolerable limits.

1.2.2.3 ASTRODYNAMICS

The future successes of both manned and unmanned space vehicle flights depend largely upon advances in orbit mechanics. At MSVD's Space Sciences Laboratory, advances are being made in many fronts associated with this need.

Laboratory scientists have formulated digital computer programs for the calculation of precise flight paths of interplanetary vehicles. Included in this project was the study of the gravitational effects of all pertinent bodies and the influence of all non-gravitational forces of the vehicle.

In another area, SSL personnel have established high accuracy three dimensional lunar trajectories that have included the gravitational effects of the earth, Moon and sun. IBM 704 programs were prepared with capabilities to circumnavigate the Moon and return as well as to orbit the Moon as a satellite.

For the United States Army, Laboratory scientists have established the orbital characteristics of earth circling passive satellites using the BRL-ARPA DOPLOC Satellite Tracking System.

To provide higher accuracy and considerably shorter computing time, the Space Sciences Laboratory has evaluated the techniques used in celestial mechanics and has established a new set of variables to describe the motion of a space vehicle on interplanetary missions. In addition, the Laboratory has prepared a composite program linking the various flight regimes encountered during interplanetary missions. Connected with the Laboratory's six degree of freedom re-entry program, this effort included the study of rigid body motions.

In addition to these areas of progress, Laboratory personnel have made important contributions to the Department's successful space testing of its three-axis stabilization system that used both the sun and the earth as reference points in successfully controlling the attitude in space of U. S. A. F. ATLAS and THOR re-entry vehicles during a major portion of their ballistic flight. The control accuracy attained on these flights could be duplicated on flights further into space, using other planets and stars as check-points.

A successful lunar maneuver will require, first, precise determination of location, and velocity of the vehicle immediately after firing; secondly, computation of the trajectory with great accuracy; and, thirdly, determination of the exact moments and locations of the vehicle when a certain type of guidance is to be actuated to achieve the mission. Space Sciences Laboratory research is contributing to our ability to successfully accomplish each of these steps.

1.2.2.4 ENVIRONMENT SIMULATION

The planning, design and development of space vehicles and satellites requires that the operation and reliability of the system be demonstrated in ground-based laboratories because of the remoteness of the space environment. At the Space Sciences Laboratory, scientists are building and using unique tools to simulate the environments of space and of re-entry for use in a wide range of projects... all designed to move man closer to manned space flight. Some of these are:

1.2.2.4.1 Air Arc Test Facilities

Arc heated aerothermodynamic test facilities are essential tools for developing and testing re-entry vehicle heat-protection systems and materials. They also provide designers with a means for assessing the performance of aerodynamic shapes such as wings and fins under high temperature conditions.

The shroud nozzle air arc is used to study the stagnation region ablation characteristics of material samples at simulated free-flight velocities of 13,000 to

17,000 ft/sec. at 100,000 ft. altitudes. The high enthalpy air flows over the specimen at 5,100 degrees K.

Two arc tunnel facilities provide relatively low heating rates with high enthalpy air to simulate flight at high altitude (low density) regimes above 200,000 ft. The supersonic arc tunnel utilizes continuously heated air that is expanded into a continuous evacuated chamber. Heat rates are in the range of 3 to 100 BTU/sq ft/sec. Relatively long tests of approximately 15 minutes are possible. Prime purpose of the hypersonic arc tunnel is to allow testing of larger specimens over higher enthalpy ranges and in lower contamination level flows. Conditions pertaining to sustained flight or soft re-entry can be simulated for over 10 minutes.

Many heat protection studies require large-scale high-temperature aerodynamic test facilities. The large air arc developed by MSVD satisfies many of the requirements.

With carbon electrodes, input to the test gas is 2500 KW; with water-cooled copper electrodes the input is 1500 KW but electrode contamination is reduced to less than one per cent. This equipment is currently used with MHD studies.

1.2.2.4.2 Char Studies

Having successfully developed ablating materials, the Laboratory is now interested in obtaining a better understanding of the associated cracking phenomena. Chars produced from basic types of ablation materials under a wide variety of conditions are being examined. Known gases are passed through induction-heated cylindrical chars under controlled conditions.

1.2.2.4.2.1 Thirty-Inch Shock Tunnel - The 30-inch shock tunnel is a blow-down wind tunnel employing a shock tube to provide a working gas of high stagnation enthalpy and pressure. Wide ranges of flow Mach number (to above Mach 22), Reynolds number, and stagnation enthalpy are available. The 22-foot driver tube,

with a 6-inch diameter, is operated either by combustion of a light gas mixture or by charging to pressure with a single inert gas. At the far end of the 112-foot driven tube, a nozzle leads to a 30-inch-diameter test section. A series of data-recording devices, including a Schlieren optical system and high-speed cameras measure a number of parameters: surface phenomena, surface heat transfer rates, axial forces, free-flight static stability, and visual flow fields. Several smaller shock tubes supplement the 30-inch tunnel or are used for specialized gas dynamic studies.

1.2.2.4.2.2 Six Inch Shock Tube – Gas Gun - A large-bore shock tube is used to accelerate a mass for collision with a stationary target, providing a controlled source of high rate of kinetic energy for impact-actuation tests. The study of structures subjected to high rates of loading and of the effects of impact phenomena are also possible.

1.2.2.4.2.3 Image Furnace - The image or solar furnace can produce steady-state surface heating to 3500 degrees K on a 1/4-inch specimen which is surrounded by a vacuum or a controlled atmosphere. Either carbon arc or solar thermal radiation may be used. The equipment is applied to investigations of radiative characteristics of metals, reactions of plastics over ranges of heat flux and analyses of pyrolytic products of irradiated plastics.

1.2.2.5 SPACE PROPULSION AND SPACE POWER

Man will need two kinds of power in space. He will need propulsive power to control and navigate his space vehicle and electrical power to operate many of the electrical equipments that will be sustaining his life and the life of the ship or satellite. General Electric Missile and Space Vehicle Department Space Sciences Laboratory scientists are pioneering new concepts and approaches to aid in achieving both kinds of power sources.

1.2.2.5.1 Space Control Propulsion

Laboratory scientists have developed, built and tested a repetitively pulsed plasma accelerator (REPPAC) that during recent 18-1/2 hour test produced enough thrust to stabilize a vehicle in space for two years. The REPPAC unit or "gun" consists of a T-shaped tube open to a vacuum and with electrodes placed at opposite ends. An electromechanical device alternately injects a measure of gas into the tube while 2,500 watts of power are supplied to a high current discharge circuit. This produces an electromagnetic field and simultaneously ionizes the gas causing it to conduct the current between the electrodes. The resultant plasma jet is magnetically accelerated at more than 22,000 mph producing thrust.

On another front, SSL personnel are investigating the possibility of constructing a continuous microwave magnetic accelerator nicknamed cyclops. Such a device, by converting the RF energy from, say an x-band klystron, could well provide a propulsive thrust having a specific impulse of greater than the 10^3 seconds that is usually agreed to be necessary for space flight application.

1.2.2.5.2 Electrical Space Power

The technical feasibility of magnetohydrodynamics (MHD) power generation has been successfully demonstrated at the Space Sciences Laboratory and appears highly practical for small, short-duty-cycle space power applications. Laboratory personnel feel that the construction of MHD generators rated from 1 to 100 is within our present ability.

But while MHD may hold the answer to space power problems, other power generating possibilities are not being neglected. SSL scientists are investigating thermionic converters and several different types of regenerative fuel cells. Other systems like photovoltaic, nuclear and thermoelectric are also under study. Each has advantages for space projects of certain time periods and missions and each is being thoroughly investigated.

1.2.2.6 LIFE SUPPORT

The Space Sciences Laboratory is actively concerned with research into space life support, primarily in the areas of waste management, oxygen recovery, air purification and food requirements as these problems apply to open, closed and partially-closed space life support system. Of all research being conducted by Laboratory personnel in the areas perhaps the most interesting is associated with oxygen and water recovery.

1.2.2.6.1 Oxygen Recovery

Space Sciences Laboratory scientists are convinced that a completely closed man-algae gas exchange cycle is open to engineering solution for use in space flight. From a biological view, sufficient information is known concerning the photosynthetic mechanism of algae. However, from an engineering view, several key problem areas have been identified by SSL personnel that need study in depth. For example:

Selection of the light energy source: The actual chamber geometry; Gas exchange and separation techniques; And the fundamental differences resulting from operation of a gas-liquid system in zero-gravity environment.

As an increasing amount of information is gained by Space Sciences Laboratory scientists on photosynthetic gas exchange and on other methods for producing and supplying oxygen, it appears certain that this ecological problem can be solved through continuing research.

1.2.2.6.2 Water Recovery

Man must inject a greater volume of water than any other liquid or solid in order to sustain life. Since roughly 1, 000 pounds of thrust is required to launch a pound of payload into space providing water in a completely closed or partially closed life support system becomes a vital problem.

Studies at the Space Sciences Laboratory have proven the feasibility of one approach to this problem.....the recovery of water from urine. This approach is built around an apparatus which is basically a vacuum pyrolytic catalysis operation in which body wastes are vaporized and then condensed after the vapor has been pyrolized in the presence of oxygen and a catalyst, yielding H_2O, CO_2, N and oxides of trace elements. The technique does not require any additives, and assuming utilization of solar energy and the vacuums existing in space, does not require high energy inputs. A relatively large amount of potable water has been produced by the Space Sciences Laboratory using this technique and it has been free of odor, taste, color, bacteria and known toxic materials.

As the need continues to grow for bold solutions to problems of life support in space, the Missile and Space Vehicle Department's Space Sciences Laboratory will conduct further studies and experiments all aimed at helping to move man closer to manned space flight.

1.2.3 Structure and Material Experience

To meet requirements of the APOLLO program, MSVD will draw on structural and material experience from re-entry vehicle, satellite and space technology, and its Advanced Structures Program. As a result of these programs, the following applicable skills have been developed:

(1) The ability to design complex structures using advanced metallic and/or plastic materials and working to minimum weight requirements.

(2) The ability to control weight and balance of complex assemblies within extremely close limits during the design phase.

(3) The ability to package a multitude of components and subsystems within a given vehicle by achieving packaging density factors equivalent to the industry state-of-the-art.

(4) The ability to test complete structural systems in the Department's own laboratory by applying the proper combination of inertial, thermal and aerodynamic loadings.

1.2.3.1 HEAT SHIELD EXPERIENCE

The General Electric Company is presently manufacturing pyrolytic graphite of the high-density type. Extensive studies have been initiated to determine the feasibility of using graphite for leading edges; also, studies are underway of pyro-graphite, carbon graphite, graphite impregnated with aluminum, and pre-stressed graphite re-enforced with tantalum rods.

MSVD has conducted numerous theoretical studies to determine mass and heat transfer on a variety of re-entry vehicle configurations. Boundary layer studies on ablation phenomena, including physiochemical considerations, have also been performed. Other work has included analysis of the aerodynamic heating of blunt hypersonic glide vehicles, analysis of the heating of the leading edges of wings and fins, and evaluation of the attenuation of signals transmitted from bodies moving at hypersonic speeds. Various passive and active heat protection systems were examined to determine their applicability to a variety of heat flux-time environments typical of a wide range of ballistic and glide vehicle re-entries. Heat fluxes up to 8000 Btu/ft sq/sec, and heating times up to 6000 seconds were considered. The systems studies included:

Solid heat sink	Liquid metal cooling
Ablation	Film cooling
Point-mass addition	Radiation cooling
Transpiration cooling	

In all of these studies, the results obtained from actual re-entry vehicle flight testing and piggy-back experimentation flights have been of great value in evolving workable advanced heat protection systems.

G-E MSVD is pre-eminent in the development of flight-proven heat protection systems. The research, design, and development information obtained and the techniques developed during the flight-proven re-entry vehicle programs previously outlined ensure a high capability with respect to the development of a heat protection system for the APOLLO program.

Using various facilities, over one-thousand different materials have been investigated by G-E MSVD to determine their erosion characteristics and structural adaptability as ablation materials. Of these, a number have been flight tested, and manufacturing techniques have been successfully developed in their fabrication.

The successful recovery of the Discoverer re-entry vehicle, the NERV re-entry vehicle, and various experimental vehicles, plus the repeated successful performance of the Operational Mark 2 and Mark 3 re-entry vehicles attest to G-E MSVD's capability in developing re-entry heat protection systems.

1.2.3.2 STRUCTURAL DESIGN EXPERIENCE

The operational Mark 2 re-entry vehicle, a conventional light metal structure, has been evaluated in the Structures Laboratory of MSVD for vibration and sustained loads, on complete system test units in ground cycle tests, and on a number of R&D flights. Not a single instance of structural deficiency has arisen in the Mark 2 program.

The experimental RVX-1 vehicles utilize magnesium castings and conventional light metal structural design. The heat protection materials are applied directly to the structure by techniques specially developed for this purpose. Packaging of subsystems on shelves or trays which are easily removable for checkout is a feature of this design. Design and manufacturing techniques for larger vehicles were developed for the full-scale RVX-2 re-entry vehicle. Magnesium castings and conventional built-up structure are used also on the second-generation re-entry vehicle. Weight and balance control to maintain the critical inertial

characteristics of the vehicle within required limits is accomplished by a weight control and monitoring function during design, assembly, test and preflight check-out of the vehicle.

The Mark 3 and Discoverer programs involved complex structures and metallic/plastic materials. The Mark 3 Re-entry Vehicle is a highly advanced structure, employing a large complex, magnesium-thorium sand casting for the entire flare structure. This accomplishes the structural tasks, serves to mount many components, and provides cutouts for antennas, all at minimum cost and weight. The Discoverer Shield and Forebody Structure, Figure B-16 is an all-plastic item, involving three separate fabrication processes. Glass layups, tape-wound overlays, and a nose cap in the form of overlapping shingles meet ablation and minimum weight requirements.

The ability to control weight and balance is demonstrated on the Mark 2 and Mark 3 re-entry vehicles. Weight tolerances are being held to ± 1 percent, and longitudinal and lateral center of gravity variation to about ± 0.1 inch. The control of weight and balance within these limits has been maintained with more than 100 components in the Mark 2.

Very dense packaging was achieved on the Mark 2 and the RVX-1 Re-entry Vehicles (Figure B-17) through extensive use of mockups, non-dimensional drawings on stable material, and rigid attention to tolerance buildup of structural elements.

1.2.3.3 STRUCTURES LABORATORY

The Structures Laboratory, an integral part of MSVD's Vehicle Engineering group, uses advanced environment testing methods on structures. On the Discoverer program, for example, several shields have been subjected to simultaneous application of pressure and inertial loads. When the proper heat pulse is applied, these tests prove the adequacy of the structure/heat protection shield for the anticipated environment. From simple bracketry elements to full size space and

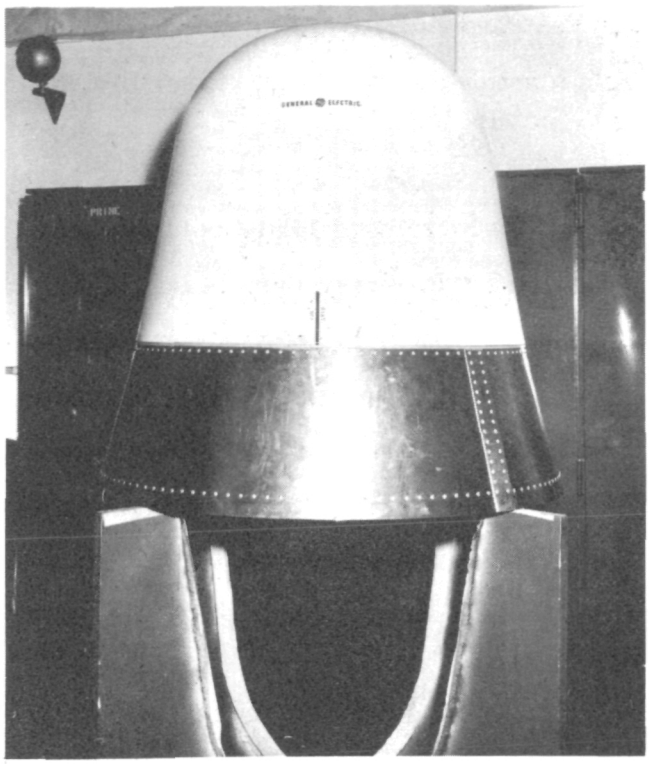

Figure B-16. Discoverer shield and forebody structure

re-entry vehicles, the laboratory programs evaluate a broad spectrum of MSVD developmental hardware.

Evaluations of prototype hardware have been conducted in the MSVD Structures Laboratory in support of the re-entry vehicle stress analysis and design effort. Such programs have included evaluation of structural performance under high-intensity thermal inputs, high-level vibration and acoustic excitation, high-g deceleration loadings, and static testing to destruction of full-scale re-entry vehicles. A substantial amount of work has been done to optimize a design for aerodynamic control surfaces, especially for solid cantilevered sections such as the leading edges of fins.

1.2.3.4 SOLAR CELL ADHESIVES

Adhesives are under development to bond the radiation filter to the face of the solar cell, and the cell to its supporting substructure. Test results at room temperature

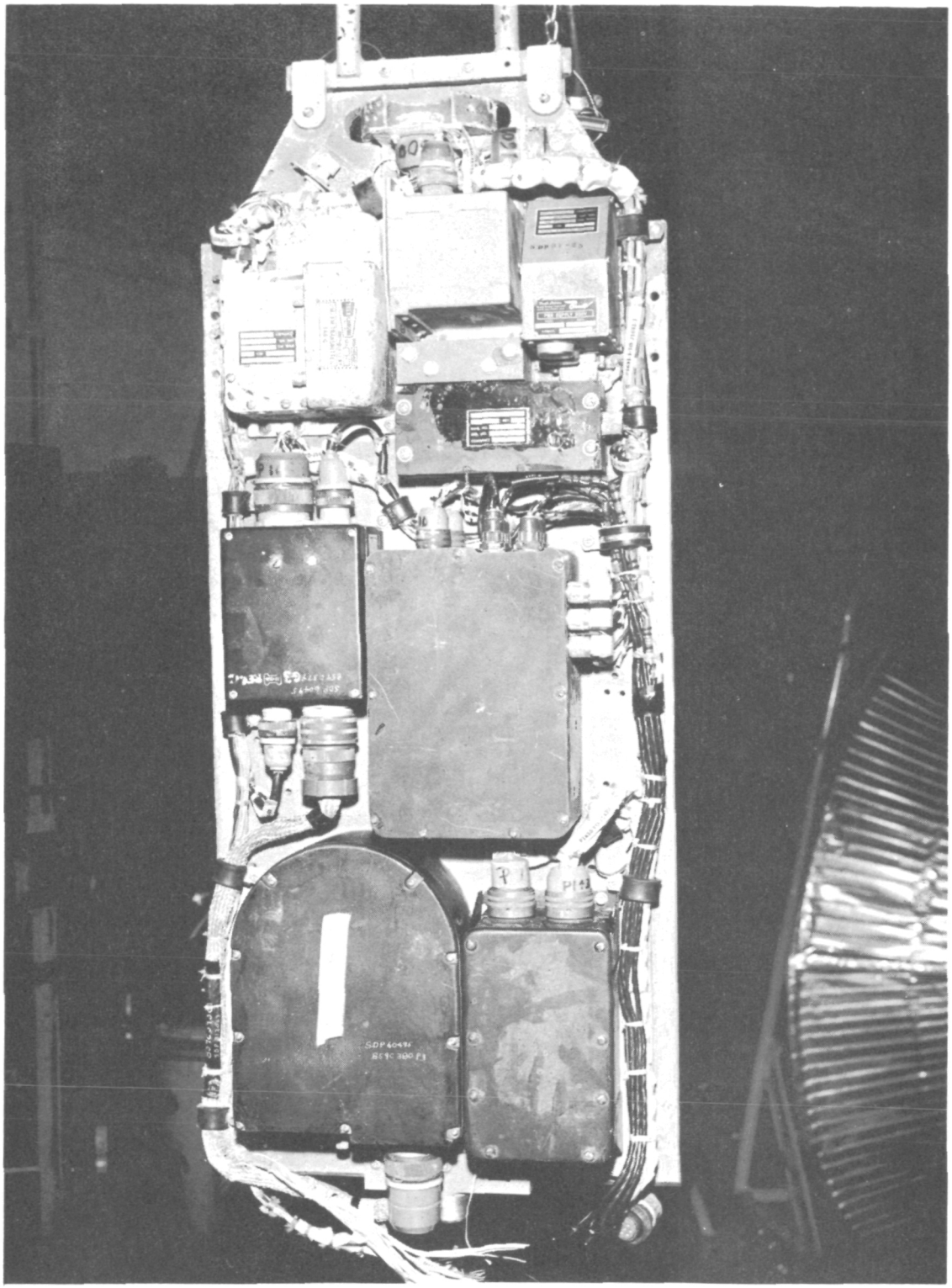

Figure B-17. RVX-1 instrumentation tray recovered from flight

indicate that one adhesive is elastic to the extent that the supporting substructure material can be subjected to full yield without damage to the cells.

1.2.4 Guidance and Control Subsystems Experience

1.2.4.1 ATTITUDE CONTROL

Since 1955, MSVD has worked continuously on the improvement and simplification of the control systems for re-entry and space vehicles. This experience is shown in Figure B-17a. The first MSVD-designed control system, the Mark 1 position control system, was devised to stabilize the attitude of the re-entry vehicles immediately after separation. This attitude was referenced to a three-axis, free gyro from which corrections were derived to operate stabilizing reaction jets. This system was analytically evaluated and simulation studies were conducted. This system was analytically evaluated and simulation studies were conducted. This system was replaced by the Mark 2 "rate damping" system which utilizes aerodynamic stabilizing and damping forces with the rate control mechanical damping forces. The Mark 2 system resulted in a great simplification over the previous Mark 1 system.

To demonstrate the reliability of the Mark 2 system, a series of experimental vehicles (Mark 2, Mod 1E1 through 1E8) were designed and built to obtain deliberate backward re-entry flight paths. The stabilization systems conceived for these vehicles utilize horizon seeking infrared devices for two-axis stabilization and various schemes for third-axis stabilization, utilizing sun trackers, magnetic field detectors, inertial components, etc. Several open loop and two closed loop flight tests have been successfully completed with two axis-stabilization systems. In July, 1959, the first flight with a three-axis stabilization system, using infrared horizon seekers and suntrackers, was successful in every respect. A motion picture camera in the Mark 2 re-entry vehicle recorded the successive steps of stabilization as the flight progressed. Considerable analysis and simulation is underway to optimize such stabilization systems for application to other vehicles. Some altitude control equipments are shown in figures B-18 through B-22.

PROGRAM	STABILIZATION	GUIDANCE
MARK I R/V	AXIS GYRO POSITION	
MARK 2 R/V	RATE DAMPING SYSTEM	
MARK 2 SPACE LABS	EARTH REFERENCE (HORIZON SCANNER, MAGNETOMETER) SOLAR REFERENCE (SUN SENSOR) COLD GAS REACTION JETS	
RVX-2A	SPIN STABILIZATION (SMALL ROCKETS)	
MARK 3 R/V	SPIN SEPARATION SYSTEM	
DISCOVERER R/V	SPIN STABILIZATION (SMALL ROCKETS)	ORBIT EJECTION (SOLID PROPELLANT ROCKET)
MARK 3C TP	EARTH REFERENCE (HORIZON SCANNER) INERTIAL REFERENCE (RATE GYRO) COLD GAS REACTION JETS	STABLE PLATFORM TEST ON CENTRIFUGE HIGH ALTITUDE RADAR MAP MATCHING
ADVENT	EARTH REFERENCE (HORIZON SCANNER) SOLAR REFERENCE (SUN SENSOR) FLYWHEEL AND COLD GAS REACTION	ORBIT CORRECTION PROPULSION
NIMBUS	EARTH REFERENCE (HORIZON SCANNER) SOLAR REFERENCE (SUN SENSOR) ORBITAL REFERENCE (ORBITAL RATE INTEGRATING GYRO)	
OAO	STAR REFERENCE (STAR TRACKER), ARC SOLAR REFERENCE (SUN SENSOR)	
MARK 6 R/V	SPIN AND SEPARATION RE-ORIENTATION SYSTEM	
NERV	DE-SPIN SYSTEM ("YO-YO" WEIGHTS)	
SAMOS II	SPIN STABILIZATION HORIZONTAL STABILIZER	ORBIT CORRECTION, DE-ORBIT CONTINUOUS SYSTEM
GSS	EARTH REFERENCE (HORIZON SCANNER) STAR REFERENCE (STAR TRACKER)	ORBIT CORRECTION PROPULSION ORBIT POSITION SENSOR (STAR TRACKER) RE-ENTRY GUIDANCE (INERTIAL PLATFORM)
APOLLO	EARTH/LUNAR REFERENCE (HORIZON SCANNER) STAR REFERENCE (STAR TRACKERS) SOLAR COLLECTOR REFERENCE (SUN SENSORS)	TRAJECTORY POSITION SENSOR (STAR TRACKER) TRAJECTORY CORRECTION PROPULSION LUNAR ORBIT/DE-ORBIT GUIDANCE ABORT/ESCAPE GUIDANCE — RE-ENTRY GUIDANCE LANDING GUIDANCE

Figure B-17a. MSVD Guidance and Control Experience

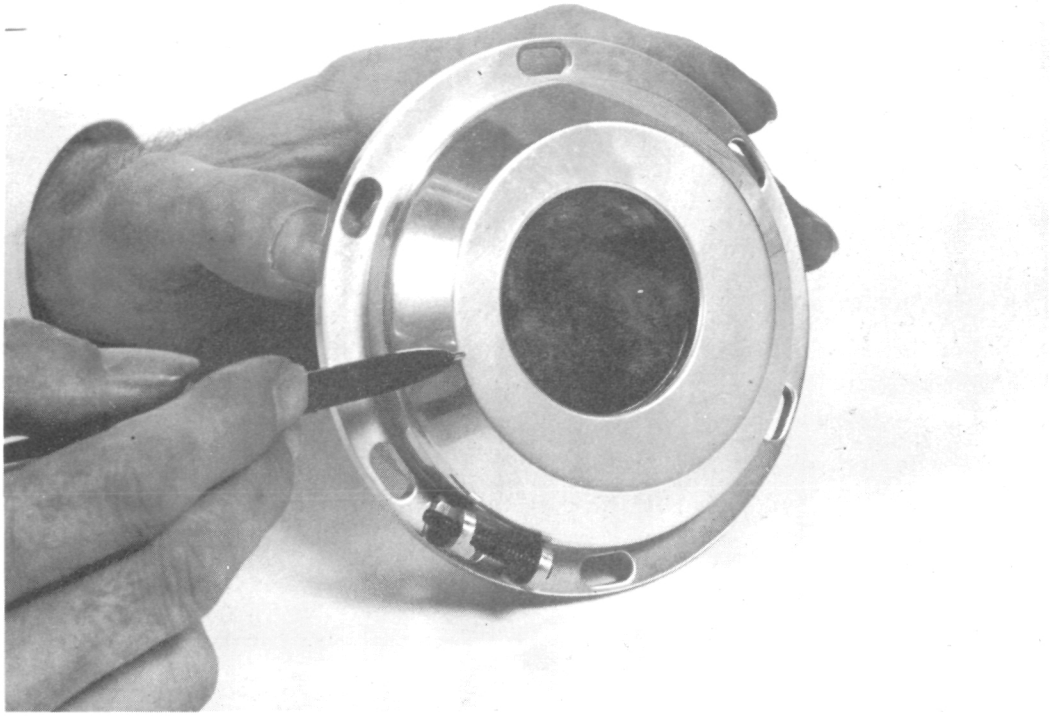

Figure B-18. Infrared horizon seeker for 3-axis stabilization system.

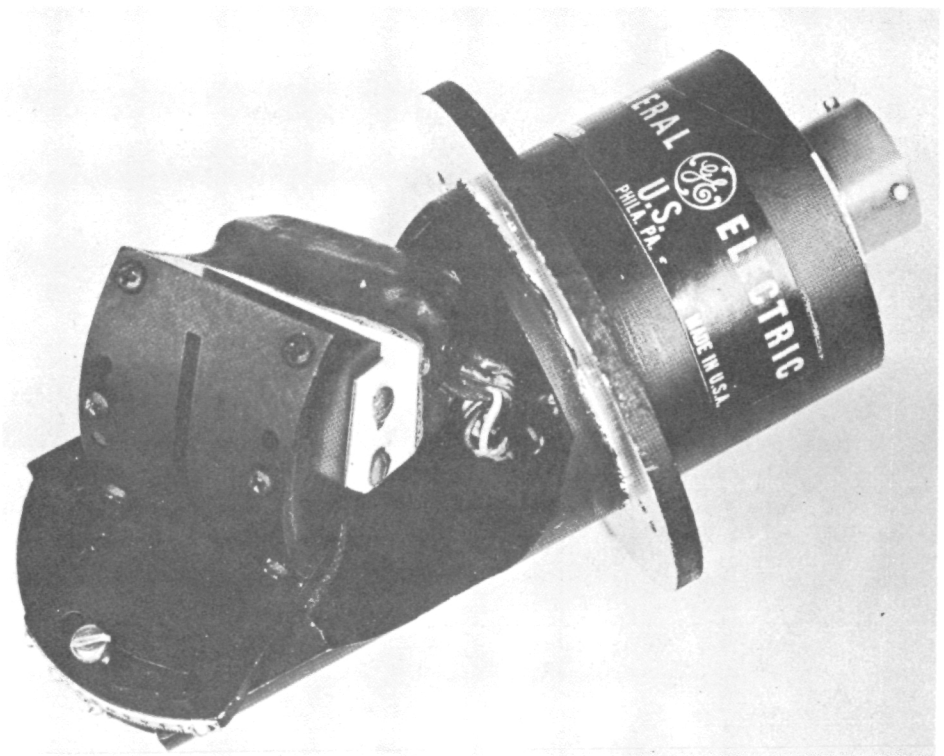

Figure B-19. Sun tracker for 3-axis stabilization system.

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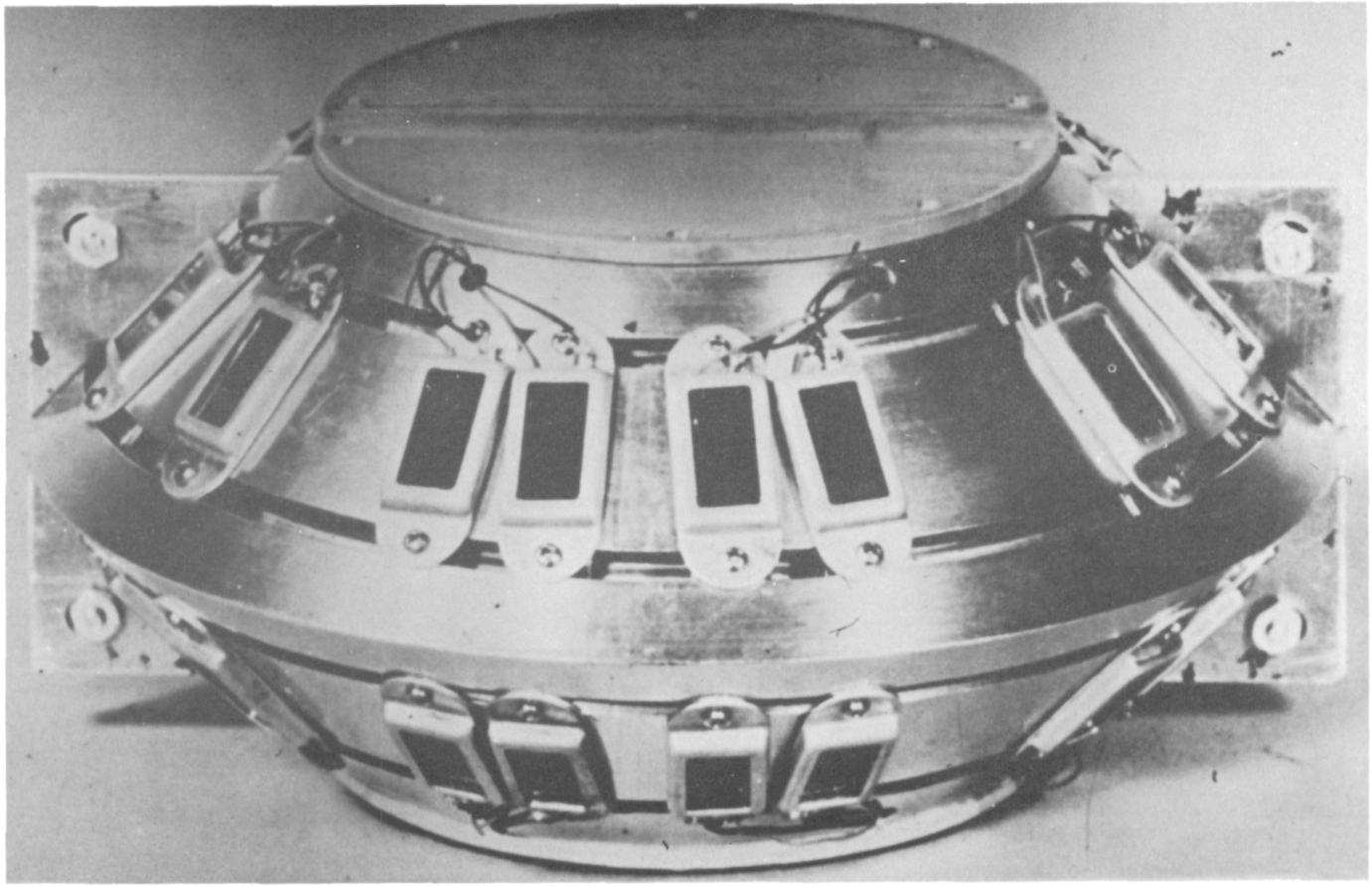

Figure B-20. Yaw axis sun sensor

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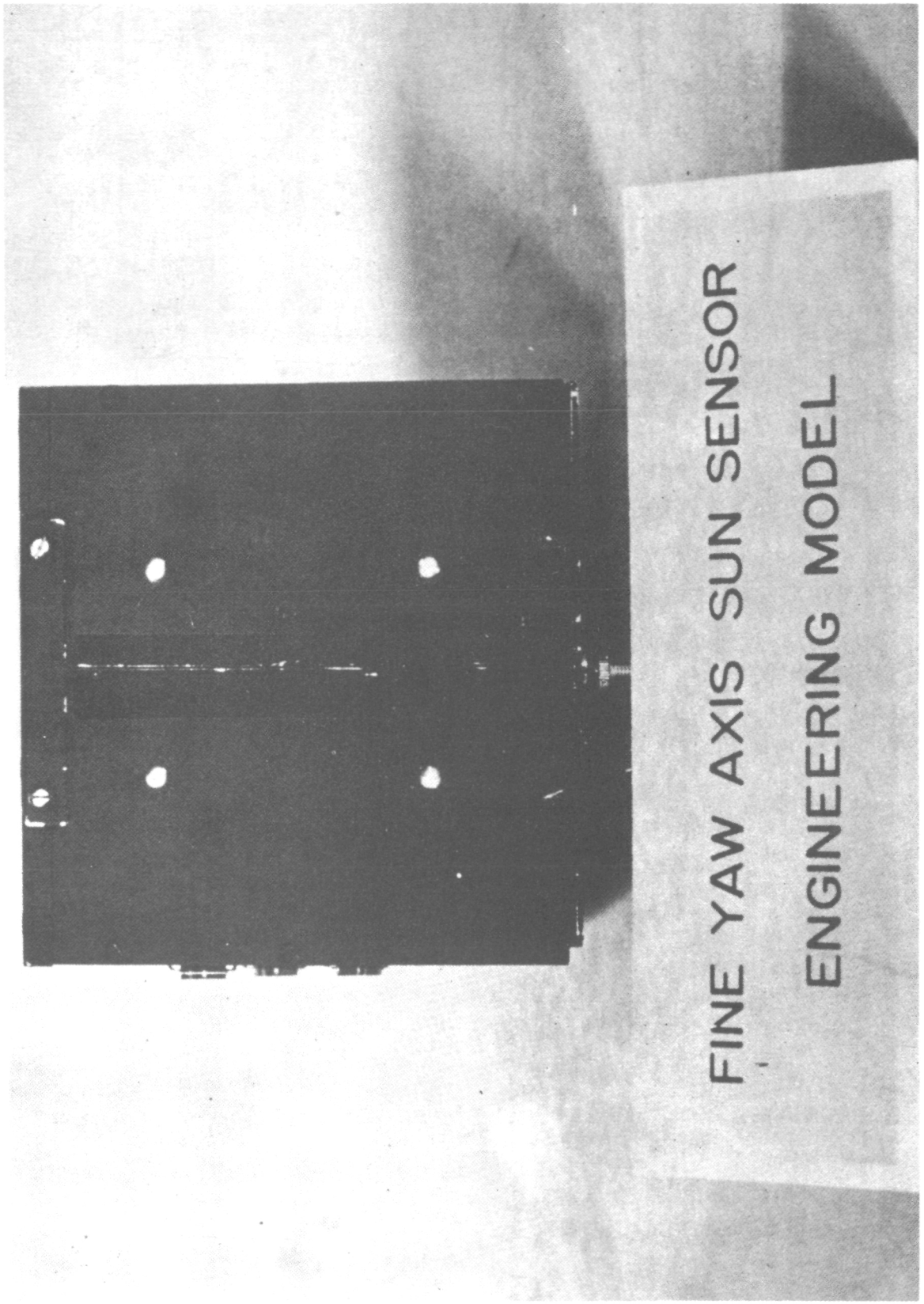

Figure B-21. Fine yaw axis sun sensor

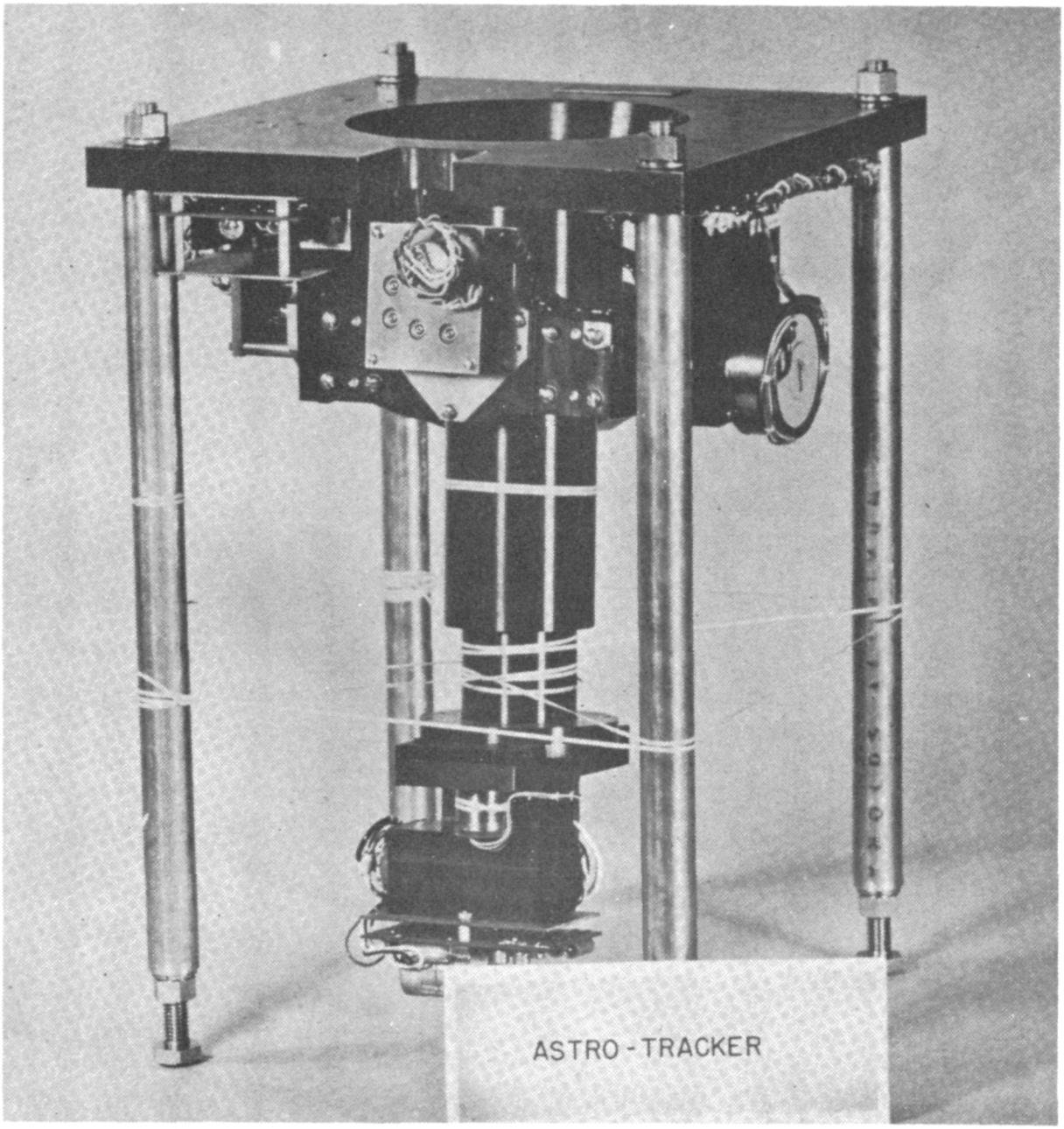

Figure B-22. Astro tracker

1.2.4.2 PROGRAMMED RE-ENTRY CONTROL

A number of programmed re-entry control systems have been developed by MSVD. In the RVX-2 experimental re-entry vehicle program and the Skybolt air-launched ballistic missile program, spin stabilization control is achieved by spinning the re-entry vehicle about the longitudinal axis with an impulse generated by two solid propellant rockets. Upon receipt of the separation signal from the missile airframe, thermal batteries in the dispersion control system are activated, the rocket motors are then ignited, and the desired spin is imparted. The Mark 3 re-entry vehicle utilizes a simple torque tube device. A torque of 5000 inch-pounds is applied prior to mating to the missile airframe and the re-entry vehicle is held in the torque position until separation. At separation the torque tube unloads and spins the re-entry vehicle to about 10 rpms. This spin overcomes any undesired lifting effects and aids in the reduction of dispersion.

1.2.4.3 TERMINAL TRAJECTORY CONTROL

For the Mark 3C terminally guided re-entry vehicle, a control system was devised consisting of both an attitude control and terminal trajectory control in combination with a map matching system to correct for errors introduced earlier in the system by the powered flight guidance and the geophysical unknowns. The attitude control system provides stabilization for the inertial guidance stable platform to prevent tumbling which results from: (1) initial angular rate and separation and/or retro rocket mis-alignment, (2) angular errors existing after the angular rate has been removed, (3) angular momentum produced by rotating equipment, and (4) limit cycle oscillation. The initial flight test of the Mark 3C Test Program proved the successful operation of the attitude control system.

1.2.4.4 ORBIT EJECTION

The orbit ejection control system developed for the DISCOVERER orbital vehicle employs spin stabilization to control the attitude of the re-entry vehicle during ejection from orbit. Prior to re-entry, the vehicle is despun to maintain low

angular rates during re-entry to the atmosphere. The spinning and despinning torques are derived from small solid-propellant rocket motors that have been qualified and test fired at the Company's Malta Test Station and have been flown. This vehicle is the only re-entry vehicle in the Free World to date that has successfully re-entered from orbit. The weight of each rocket is 1.4 pounds with a total impulse of 15 pounds per second + 3 percent; a difficult tolerance to achieve in such a small rocket.

1.2.4.5 SATELLITE ORBIT CONTROL

A new method of circularizing elliptical orbits has been developed by MSVD engineers. This system, called GESOC (General Electric Satellite Orbit Control), consists of two basic elements: a computer and a small solid-rocket gas generator. GESOC uses an infrared sensor to determine orbit parameters. The system is scheduled for early flight test. The control system has a cluster of four nozzles positioned in opposite directions. The generator supplies gas to any number of the nozzles as commanded by the computer. GESOC can compute the necessary impulse and initiate the correction by firing a solid or liquid-fueled reaction thrust system at the proper point in orbit. The computer is shown in Figure B-23.

1.2.4.6 PULSED PLASMA ACCELERATOR CONTROL

A working model of a pulsed plasma accelerator was developed by the MSVD Space Sciences Laboratory to demonstrate the feasibility of pulsed plasma propulsion for spacecraft attitude control. The device produces high specific impulses by electromagnetically accelerating a low density gas. Motor is a high current spark circuit using the repelling magnetic field set up by its own current to elongate the spark. The resulting high exhaust velocities of the gaseous fuel provide usable thrusts.

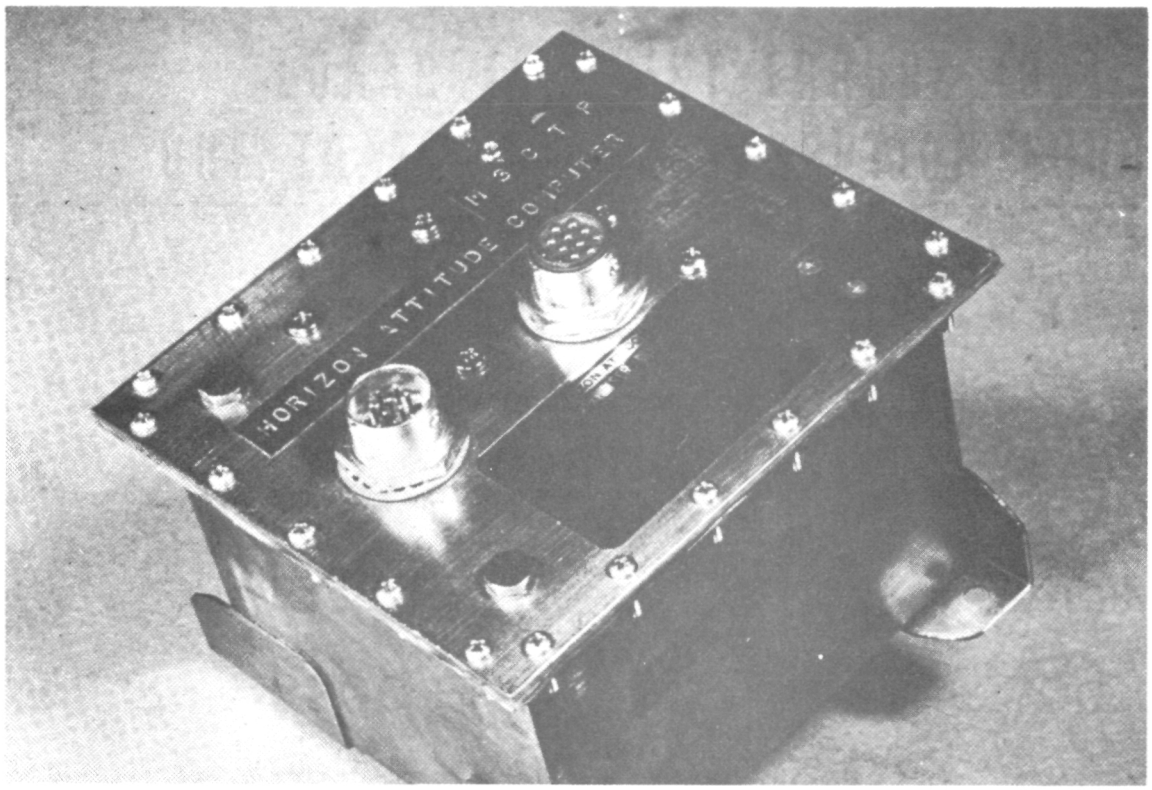

Figure B-23. Horizon attitude computer

1.2.4.7 FLIGHT SIMULATION

Extensive computer simulation was used in the design of various control systems. A six-degree-of-freedom analog simulation was used to test variations of cross products of inertia, gas energy supply, torque-to-inertia ratio, and other variables. A three-degree-of-freedom study was conducted with a completely simulated thrust system – a three-axis flight table connected with and operated by an analog computer programmed to compute inertial angles in real time. This study evaluated the adequacy of the reaction system and examined the effects of rate gyro cross coupling with sensitivity. One-degree-of-freedom simulation was done using a complete mechanical simulator with actual components. Techniques were developed for simulating the zero friction conditions of ballistic flights.

Under contract to WADC, MSVD conducted a study of manned re-entry control systems. This study will lead to recommendations for control systems hardware for manned vehicles returning to the atmosphere from orbit. In order to provide the necessary data to control systems designers, this study included investigations into many influencing factors such as the re-entry heating problem, the re-entry trajectory, vehicle aerodynamics, powered flight and gliding, human performance capabilities, manned control versus automatic control for certain functions, control hardware requirements, and the like.

From the foregoing descriptions of MSVD progress in design, development, and fabrication of space vehicle and re-entry vehicle control systems, it can be seen that the Department has had a great deal of valuable experience in this area. One of the critical technical requirements of the APOLLO program will be the delineation of control system parameter and the specification of control system hardware. GE-MSVD feels competent to meet this requirement with maximum results based on its strong technical background and know-how in vehicle control systems.

1.2.4.8 HIGH PRESSURE, STORED GAS TORQUE GENERATORS

Stored-gas, torque-generator systems have been flight proven on the Mark 1, 2, and Mod 1E control systems. Three general types of stored-gas systems have been designed: (1) a regulated, constant-thrust control torque system, (2) an unregulated, high thrust system for large initial error correction, and (3) a very low thrust system (microthrust), Figure B-24, tested to thrust levels less than 0.01 pounds.

The Mark 2, Mod 1E stored-gas system, Figure B-25, has a constant thrust of 4.5 pounds, a response of valves and tubing of less than 40 milliseconds, and a capacity of 700 pound-seconds impulse. The Mark 1 system has a thrust capacity of 700 pound-seconds impulse and a thrust of 0.5 pounds. Components of these systems have been leak-tested for over six months without significant loss.

All stored-gas systems designed by MSVD incorporate nitrogen as the working fluid since it offers weight, handling, and performance advantages over other gases. The effect of gas compressibility on reaction control has been found to be negligible.

1.2.4.9 LIQUID PROPELLANT GAS GENERATION TORQUE GENERATORS

A technique for generating gases by burning propellants has been studied in MSVD's laboratories to determine its feasibility for providing attitude control. Very valuable experience on the application and use of these systems has been accumulated. Trade-offs have been derived, such as a comparison of stored-gas systems showing the reaction time of a liquid system to be longer, since the additional "residence time", while the liquid decomposes in the combustion chamber, must be added to the overall response time. Attainable responses were satsifactory for most control applications.

In addition, a number of designs have been completed using hydrazine as a monopropellant with initial starting by RFNA. One specific design resulted in a specific

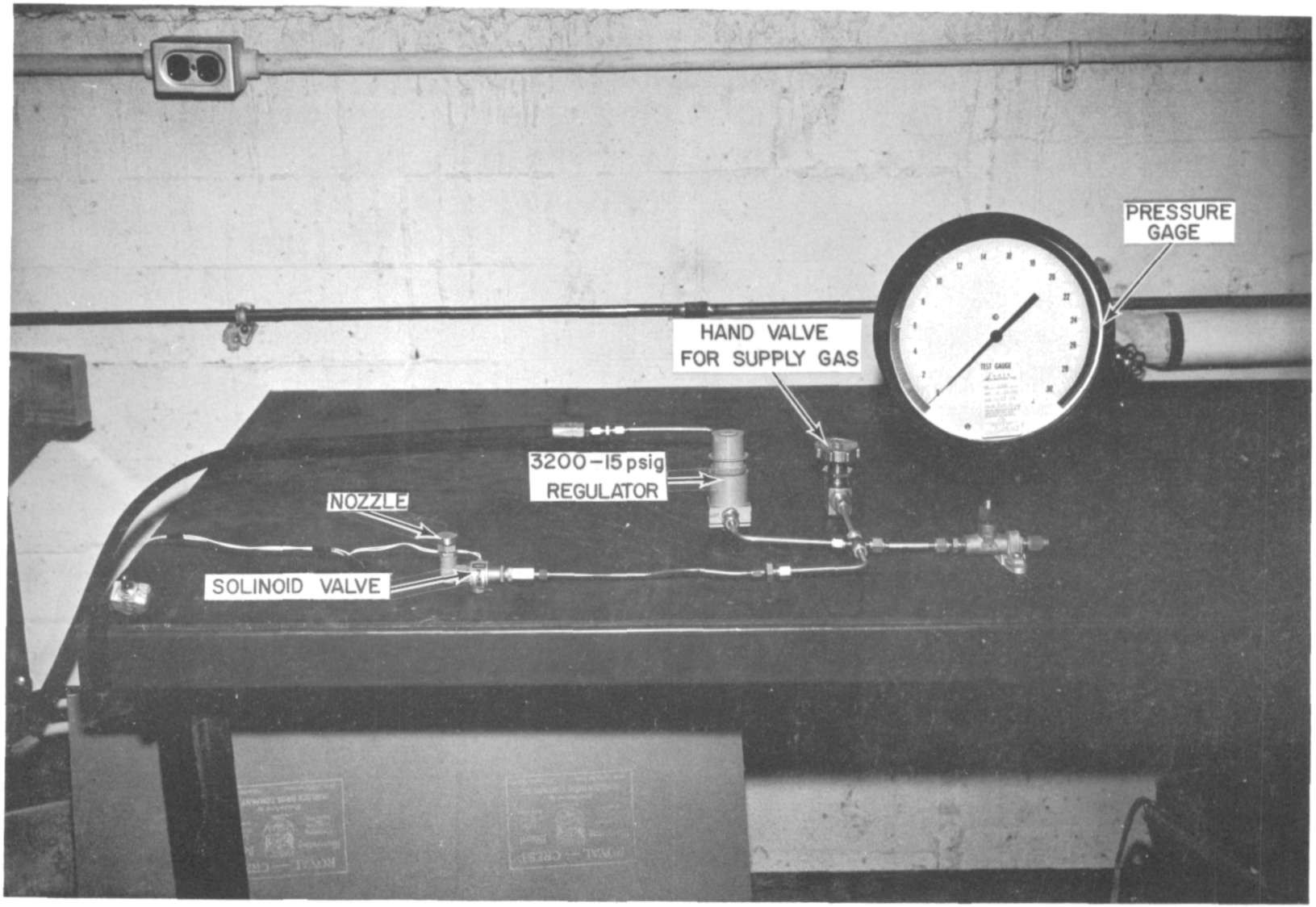

Figure B-24. Microthrust systems test

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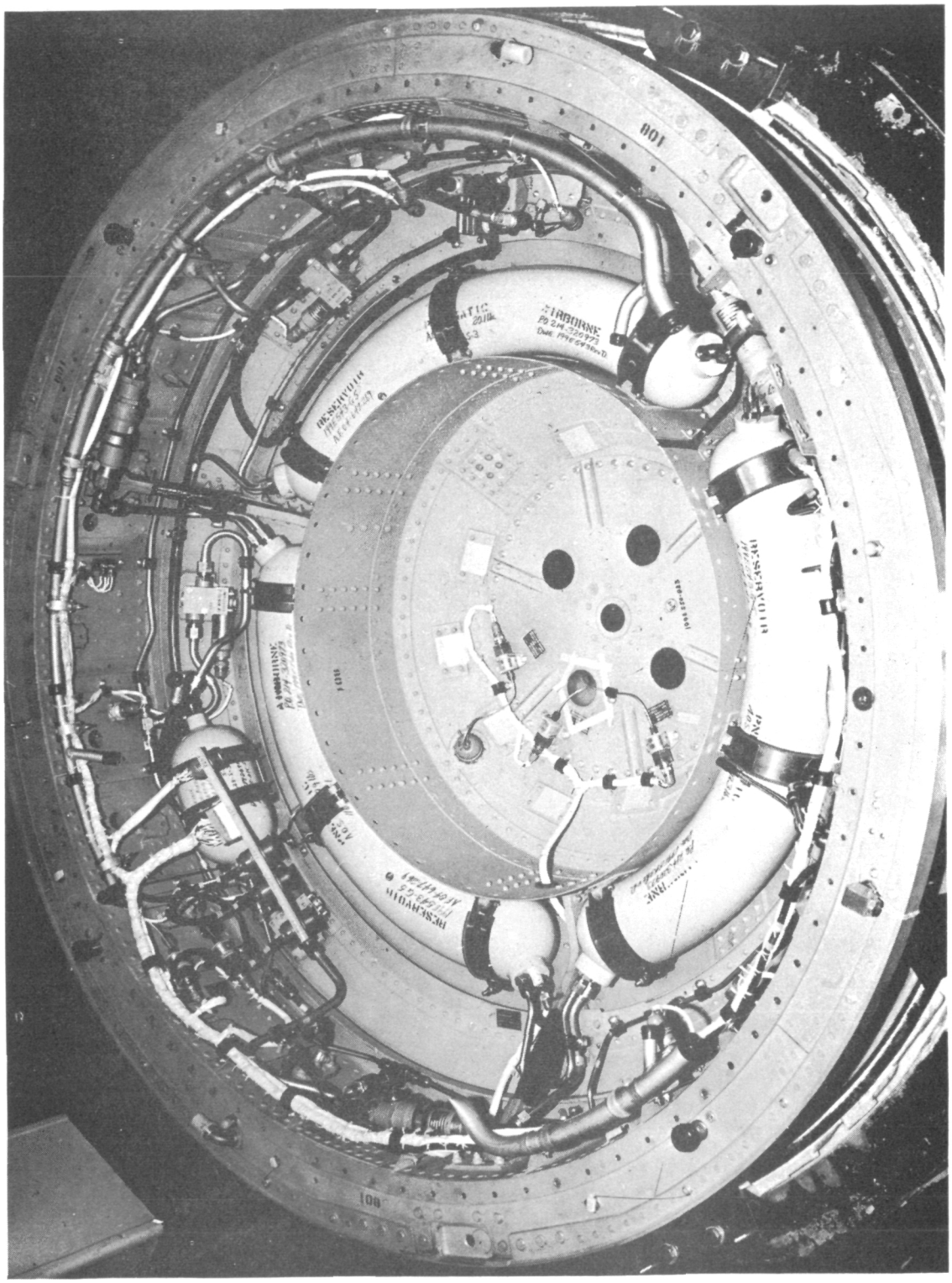
impulse in the 180-to-200 second range at 1800 degrees F having a residence of 0.25 milliseconds. Valve response is of the order of 20 milliseconds. When these are summed considering tubing delays, reaction response time is approximately 60 milliseconds.



Considerable experience has been accumulated for low impulse level systems. Stored-gas systems have been used due to weight advantage, because of the additional weight of pressurization equipment and starting and combustion chambers required by the liquid fuel systems.

1.2.4.10 SOLID PROPELLANT GAS GENERATION TORQUE GENERATOR

A system of the solid-propellant type, applicable to orbit control or attitude control, has been designed for the DISCOVERER orbit ejection-control system. See Figure B-26. It operates to correct for ejection-rocket misalignments and vehicle center-of-gravity offset. The gas-generator charge is ignited just before the ejection rocket is fired. Vehicle angular rate caused by rocket misalignment is sensed and on-off constant thrust is applied for correction. Response time of the system is on the order of 50 milliseconds. Since the total operating time is short (10 to 20 seconds) valves capable of withstanding the prevailing temperatures can readily be obtained.

In this solid-propellant system, reaction control weight increases directly with thrust-rocket misalignment. The Missile and Space Vehicle Department is engaged in a study to determine the crossover in weight and response time of a rocket-motor gimballing arrangement, or jetevators, to optimize ejection thrust control.

1.2.5 Instrumentation and Communication Subsystem Experience

In all of the re-entry vehicle programs outlined in the beginning of this section, MSVD has engaged in the design, modification, integration, installation, and subsequent monitoring of airborne and ground telemetry and communication systems. Figure B-26a lists this experience. MSVD has been responsible for the collection and processing of telemetered test data from re-entry vehicle flight tests and maintains an extensive IBM data processing and computing facility primarily for this purpose. As a result of this experience, MSVD thoroughly understands and knows how to implement telemetry requirements for APOLLO. Figures B-27 and B-28 show typical MSVD telemetry equipment used in previous flight tests.

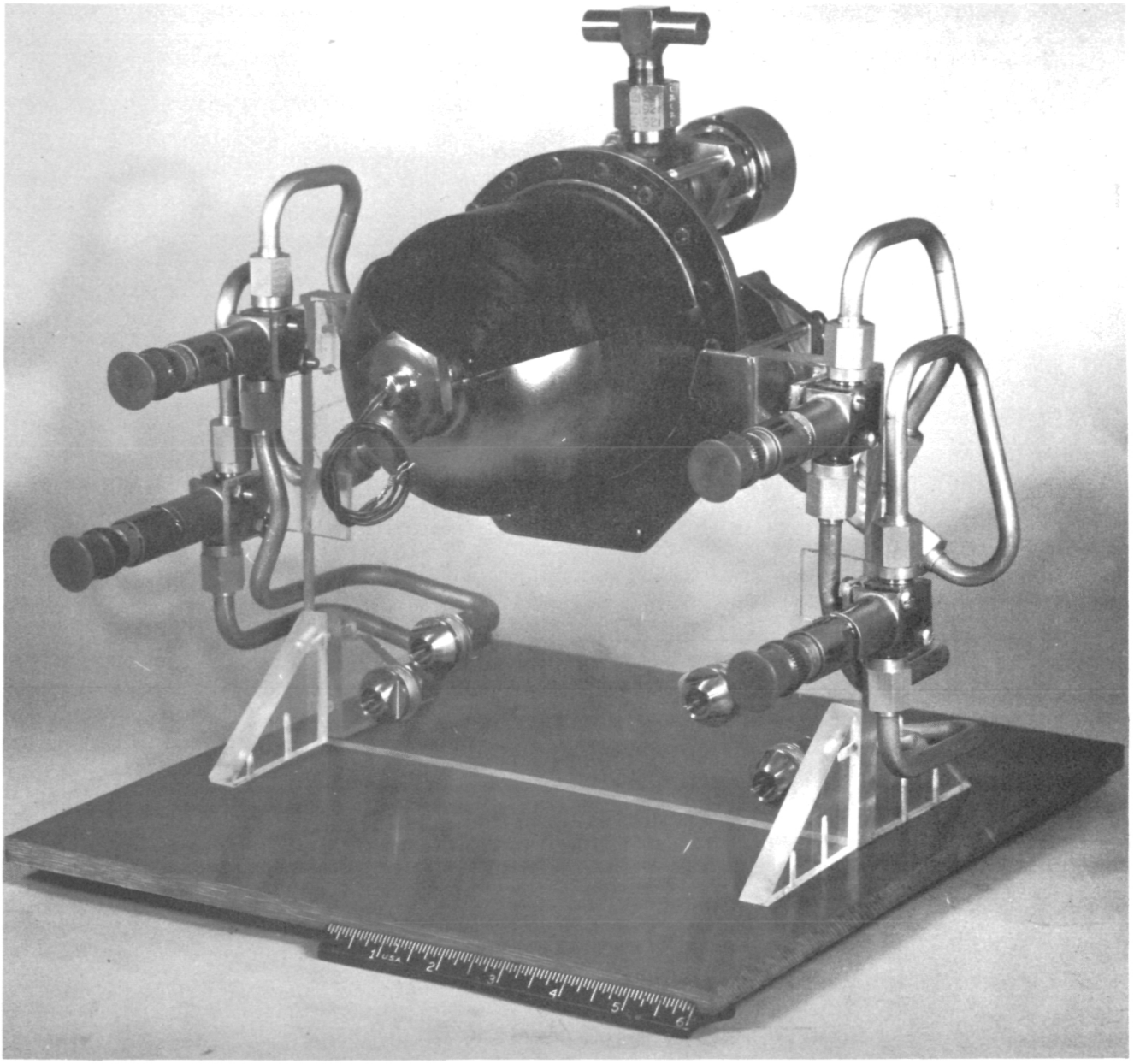


Figure B-26. Solid propellant gas generator

MSVD has been responsible for the collection and processing of telemetered test data from re-entry vehicle flight tests and maintains an extensive IBM-equipped data processing and computing facility primarily for this purpose. As a result of this experience, MSVD thoroughly understands and knows how to implement the telemetry requirements for the APOLLO program. Figures B-27 and B-28 show typical MSVD telemetry equipment used in re-entry vehicle test flights.

AREAS OF OPERATION	PROJECTS
AIRBORNE TELEMETRY, TRACKING AND COMMAND SYSTEMS	ADVENT, MARK VI, RVX-2A, SAMOS - II, SKYBOLT
GROUND STATION TELEMETRY, TRACKING AND COMMAND SYSTEMS	ADVENT, MARK VI
ANTENNA STUDIES	DISCOVERER, NIMBUS, ADVANCED R/V
CAMERA STUDIES AND CONSULTATION	BIG SHOT, SPURT
RECOVERY AIDS	DISCOVERER, GOLDEN RAM, NERV, SAMOS - II
OTHER DESIGN	SPACE SIMULATOR (OPTICS) MARK III (INSTRUMENTATION) NIMBUS (SENSOR TARGETS) GEISHA (DDA COMPUTER)

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Figure B-26a. MSVD Instrumentation and Communication Experience

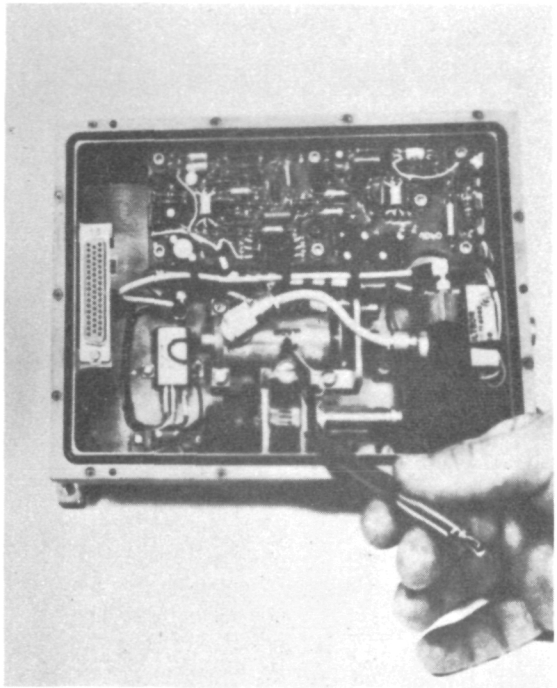


Figure B-27. Miniaturized C-band beacon for telemetry applications in re-entry vehicles

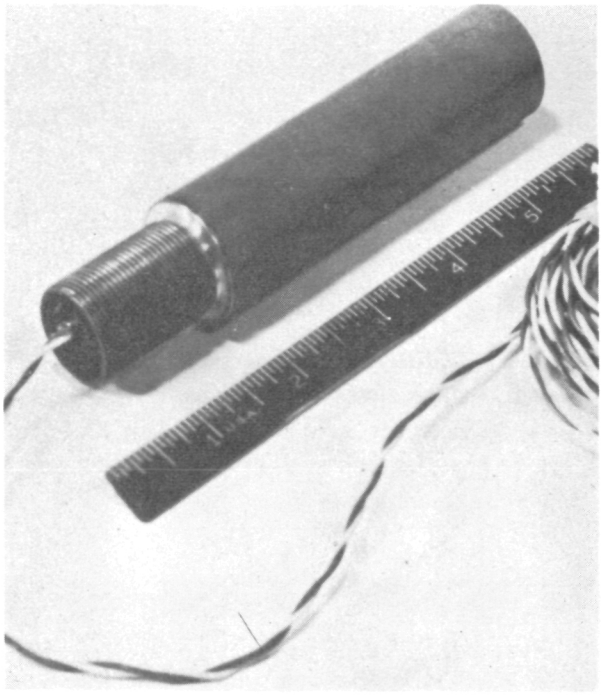


Figure B-28. Ablation detector used in measuring ablation rate during vehicle re-entry

1.2.5.1 INSTRUMENTATION

Instrumentation capability that will be utilized incorporates the knowledge and experience gained from numerous flight tests on the THOR, THOR/ABLE, Atlas programs. Re-entry vehicle telemetry has performed satisfactorily at ranges from 1100 to 5500 nautical miles. These flight tests have demonstrated the soundness and reliability of MSVD airborne instrumentation system design. The components employed in these GE-MSVD re-entry vehicle airborne instrumentation systems are the result of exhaustive environmental testing that provides reliable components for operation during the adverse acceleration, vibration, and temperatures experienced during flight.

1.2.5.2 COMMUNICATION

In the field of communications, MSVD has engaged in extensive design, development and testing activities both for the THOR and Atlas re-entry vehicles and for the Satellite programs. This experience can be categorized as follows:

- VHF telemetry; airborne and ground systems and components including FM/FM, PWM, FM, and PPM/AM
- HF telemetry; airborne and ground systems and components
- HF, VHF, UHF, and SHF antenna designs for high speed vehicles and high temperature environment
- Pulse-radar systems and, particularly, S-band and C-band beacon

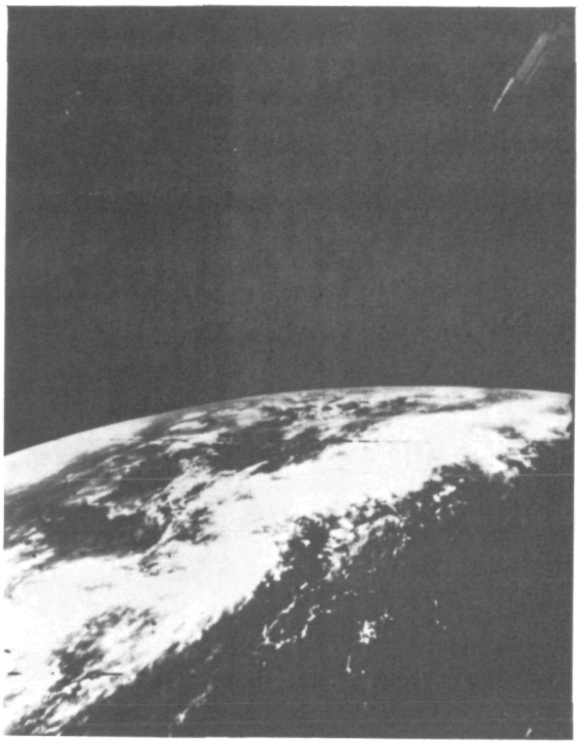
  CW tracking systems and components
- Recovery systems and, particularly, high-impact acceleration components and circuits.

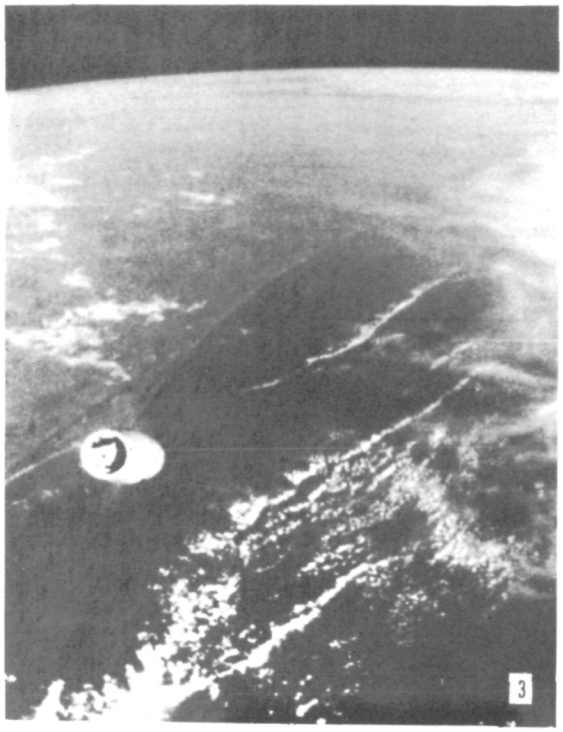
Included among the communications equipment employed in the THOR/Atlas telemetry systems are such items as telemetry and antenna components, acquisition and tracking beacons and transponders, and beacon interrogation equipment.

1.2.5.3 SPACE VEHICLE CAMERA AND PHOTOGRAPHY

Data capsules equipped with cameras have been recovered after four flights. These photographs, Figure B-29, taken by a specially designed camera are the first results of a significant step forward in the field of space vehicle instrumentation.

The space camera system, although primarily designed as a means for optically checking the flight test performance of re-entry vehicle stabilization system, proved that the space camera can be effectively used to photograph large areas of the earth surface.





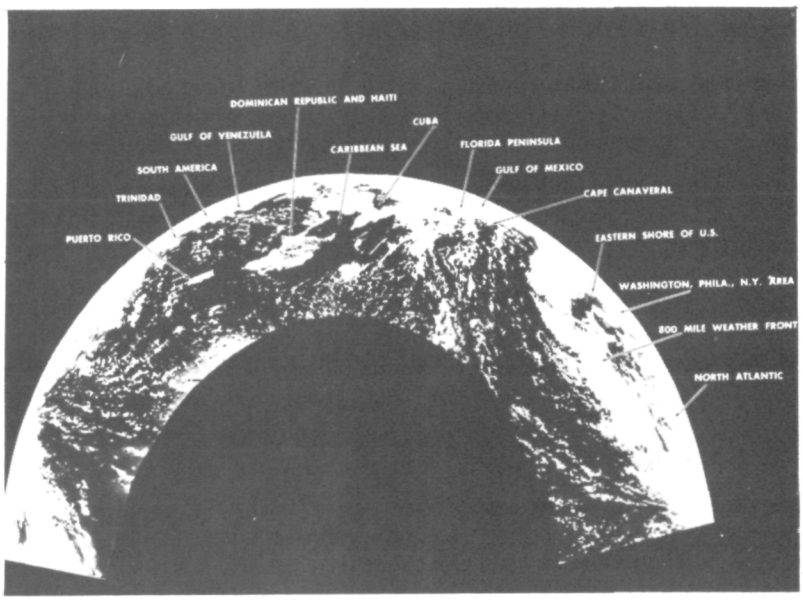


Figure B-29. Photographs of earth from space. (A) shows weather front over east coast area of United States. Note Atlas booster, upper right corner. (B) shows Florida coast; Cape Canaveral is directly behind Thor booster. (C) is a montage made from films taken during Atlas flight 5500 miles over South Atlantic at altitudes up to 800 miles

These motion pictures were very successful for the purpose intended. In addition, however, they constitute the first demonstration of successful space photography from travelling space vehicles. These pictures taken from altitudes as high as 800 miles, lent impetus and encouragement to more comprehensive undertakings by demonstrating the feasibility of meteorological and reconnaissance space photography.

1.2.5.4 SENSING AND CONVERSION EQUIPMENT

The instrumentation systems developed by MSVD for its re-entry and space vehicle programs include special sensing and conversion devices designed in-house, as well as standard hardware modified or adapted for particular installations. This equipment includes sensors for measuring ablation, char depth, temperature, pressure, vibration, acoustic noise, acceleration, and pitch, yaw and roll rates. Among the conversion equipment provided for these programs are special amplifiers, commutators, encoders, and decommutation equipment.

An outstanding example of the specialized telemetry equipment developed by General Electric is the solid-state, long-life 90 x 10 electronic commutator fully transistorized. Designed and developed in 18 months for the Mark 3 Atlas nose cone, this device is the only known 90-channel electronic commutator of its kind. See Figure B-30.

Other sensing and conversion devices developed by MSVD include such items as a miniaturized, high-level resistance thermometer, a sensor to measure ablation and char of re-entry vehicle heat shields, a visibility detector to measure respiration and EKG in biological experiments, and several different types of specialized amplifiers.

1.2.5.5 TELEMETRY

The telemetry systems on Atlas and THOR re-entry vehicles were designed to provide a variety of aerodynamic and thermodynamic data from flight tests and,

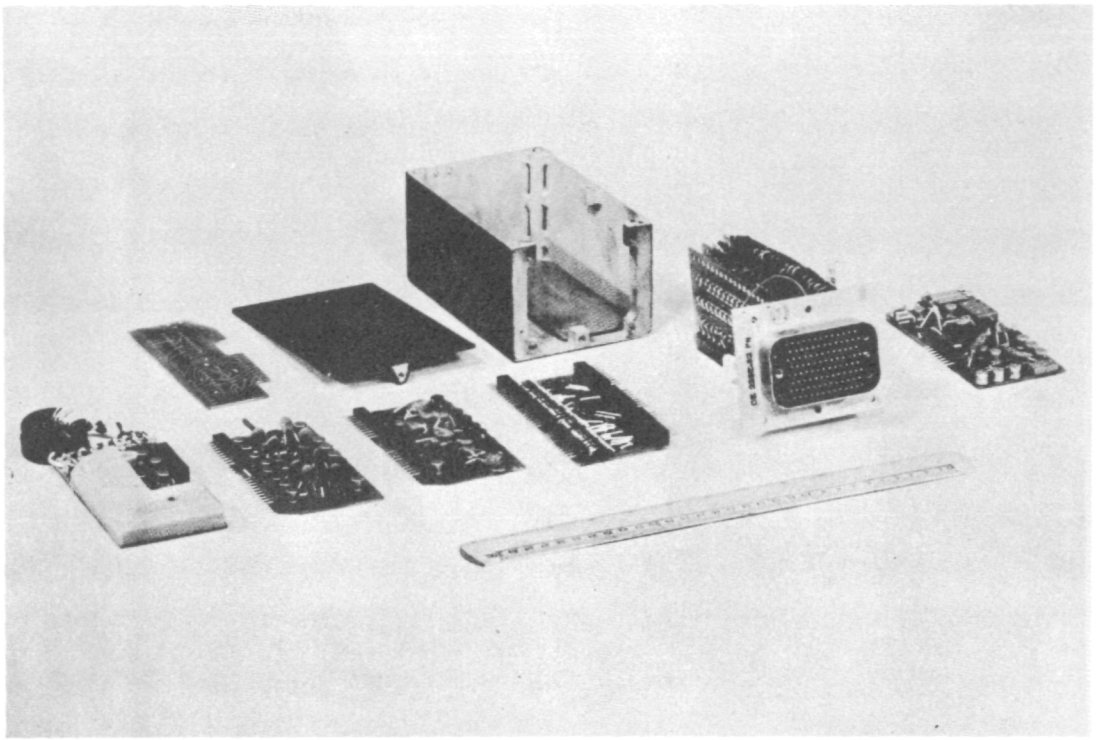


Figure B-30. 90 x 10 Commutator

also, a maximum quantity of performance information in the event of flight test failure. The best proof of General Electric competence in telemetry is the performance record of the telemetry systems in these programs. The data recovery score for MSVD is approximately 90 percent for THOR and 85 percent for Atlas, with 100 percent defined as obtaining every function to the desired accuracy for the full time period. As a result of this excellent performance record, valuable test data were obtained for analyses leading to subsequent improvements in vehicle design. The record of success and reliability achieved by MSVD telemetry systems in the ballistic missile programs results, in large measure, from the thorough qualification standards imposed for all equipment.

1.2.6 Space Power Experience

This covers significant hardware and flight experience in present-day systems such as those involving batteries and solar cells. It includes laboratory development effort of fuel cells and thermionic converters, and theoretical studies of even

more advanced concepts. As a consequence of such experience, the Department is in a unique position to apply a mature approach to space power application. Figure B-31 summarizes MSVD space power experience.

1.2.6.1 PHOTOVOLTAIC CONVERSION

The General Electric Company is carrying out basic research and development work in photovoltaic energy converters. Both the Electronics Laboratory and Semiconductor Products Department have continuing programs underway to improve basic cell designs.

Studies include experimental investigation of optically coated and un-coated cells, various bonding resins, support structure designs, and temperature control techniques. Modules in various series-parallel circuit configurations have been tested over a period of more than a year in connection with different energy-storage methods.

Coatings to minimize heat problems, radiation, and methods of meteorite protection for photovoltaic devices operating in space have been devised to improve reliability. Bonding materials suitable for attaching cells to space vehicle structures have been tested, demonstrating their capability to operate within a temperature range of -150 to 100C, as well as to meet vibration, shock, and acceleration resistance requirements.

1.2.6.2 THERMIONIC CONVERSION

General Electric's Research Laboratory carried out the basic work which led to demonstration of thermionic converter feasibility. MSVD is extending this fundamental knowledge under USAF Cambridge Research Center sponsorship (Contract AF-19(604)-5472) to improve the performance characteristics of thermionic converters. The work deals both with vacuum and vapor-type devices. Work has recently begun on a hardware development program in vacuum devices sponsored by the Wright Air Development Division of ARDC, Contract AF-33(616)-7008.

The objective of this program is to produce a 500-watt solar thermionic system employing a foldable, solar collector and including a nickel-cadmium battery energy storage subsystem. Figures B-32 through B-35 show some components of the MSVD Solar Thermionic Electrical Power System.

1.2.6.3 BATTERIES

This Department has applied primary and secondary chemical battery designs to many missile and satellite programs such as Atlas, THOR, Discoverer and Advent. These designs encompass silver zinc, nickel cadmium, thermal, silver cadmium, and mercury batteries ranging in capacities from 0.01 to 100 ampere hours.

At present, there are battery programs in progress dealing with sealed nickel cadmium batteries in areas of prolonged charge-discharge cycling; gas leakage rates; temperature ranges for cycling programs; heat transfer problems; and internal impedance.

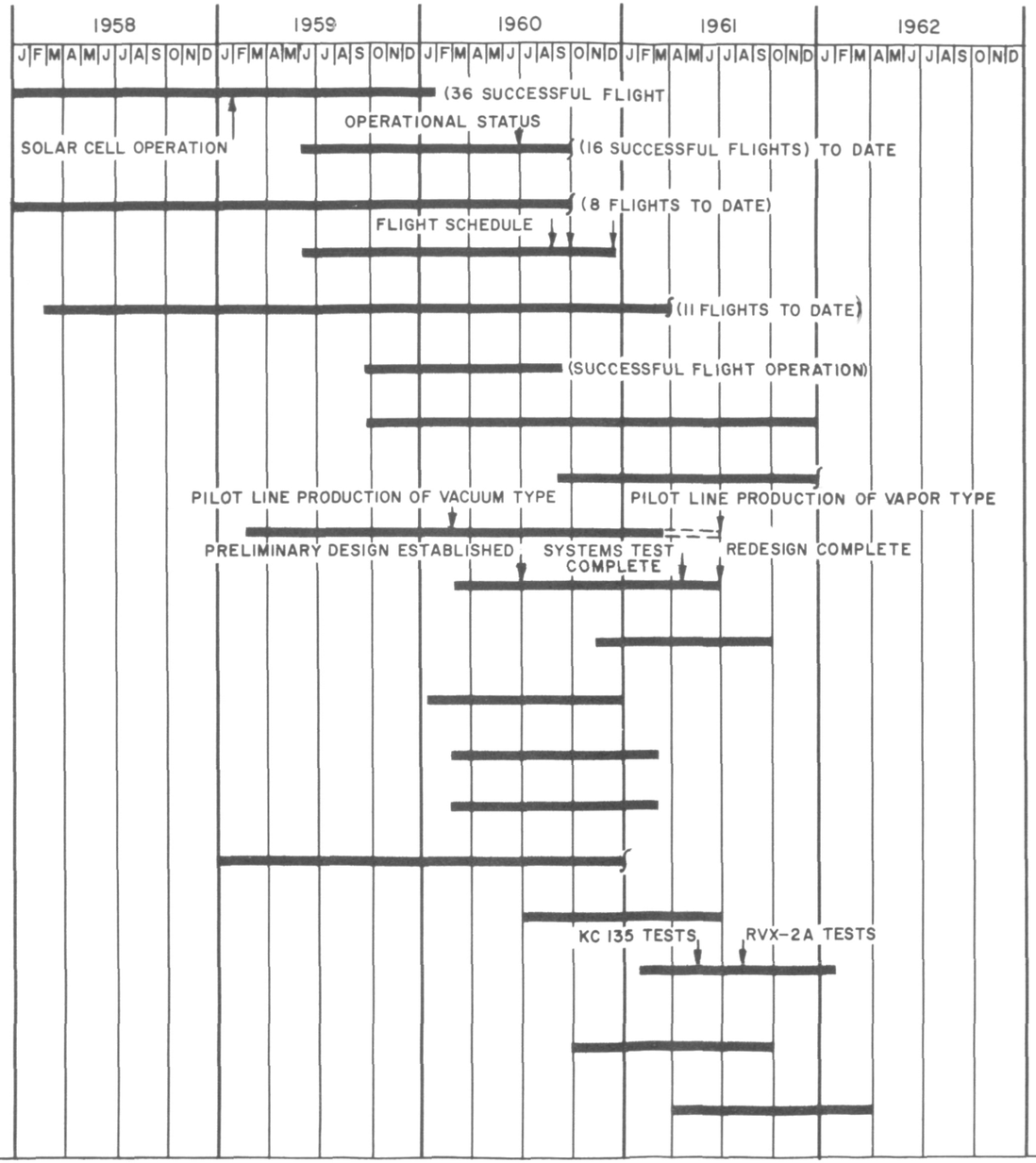
In addition, programs exist to test the latest sealed silver-zinc and sealed silver-cadmium batteries which have not as yet been placed in general use.

1.2.6.4 FUEL CELLS

Of the many types of fuel cells currently under development, one of the most promising is the ion-exchange membrane-type cell currently undergoing extensive development by the General Electric Company. This cell, which is operated on hydrogen and oxygen is similar to the standard hydrogen-oxygen fuel cell with the exception that the liquid electrolyte has been replaced by an ion-exchange membrane. See Figure B-36.

Laboratory tests have demonstrated that this type of cell can be reversed and operated as an electrolysis system to produce hydrogen and oxygen gas. The General Electric Company has operated cells in this manner, alternately charging and discharging them for a number of cycles, thus demonstrating their energy storage

MSVD SPACE POWER PROGRAMS



	SIGNIFICANT ASPECTS
◆ MARK 2 (USAF)	(1260 WH) SECONDARY TYPE SILVER-ZINC RECHARGEABLE BATTERIES-R AND D FLIGHTS PRIMARY TYPE AUTO-ACTIVATED SILVER-ZINC BATTERIES - OPERATIONAL FLIGHTS
▬ MARK 3 (USAF)	(450 WH) SECONDARY TYPE SILVER-ZINC RECHARGEABLE BATTERIES-R AND D FLIGHTS PRIMARY TYPE AUTO-ACTIVATED SILVER-ZINC BATTERIES-OPERATIONAL FLIGHTS
▬ RVX SERIES (USAF)	(740 WH) SECONDARY TYPE SILVER-ZINC RECHARGEABLE BATTERIES IST SUCCESSFUL OPERATION OF FUEL CELLS IN SPACE
▬ MARK 3CTP (USAF)	(730 WH) SECONDARY TYPE SILVER-ZINC RECHARGEABLE BATTERIES
• DISCOVERER (USAF)	(140 WH) SECONDARY TYPE SILVER-ZINC RECHARGEABLE BATTERIES (126 WH) PRIMARY TYPE AUTO-ACTIVATED SILVER-ZINC BATTERIES (75 WH) MERCURY CELLS (6 WH) NICKEL-CADMIUM BATTERIES THERMAL BATTERIES-15 VOLT TO 35 VOLT SIZES (3)
▸ NERV (NASA)	(730 WH) SECONDARY TYPE SILVER-ZINC RECHARGEABLE BATTERIES
ADVENT (USAF)	750 WATT SOLAR PHOTOVOLTAIC ORIENTED POWER SYSTEM USING SEALED NICKEL-CADMIUM BATTERIES FOR STORAGE (560 WH) 20,000 MILE ORBIT ENVIRONMENT
NIMBUS (NASA)	WILL INTEGRATE AND TEST SYSTEM
THERMIONIC CONVERTER RESEARCH (AFCRC)	MATERIALS AND TECHNIQUES APPLIED RESEARCH LEADING TO DEVELOPMENT OF VAPOR DEVICES
SOLAR THERMIONIC POWER SYSTEM (WADD)	FIRST COMPLETE SYSTEM FEATURING THERMIONICS
THERMAL ENERGY STORAGE FOR THERMIONIC (NASA/GSFC)	THERMAL ENERGY STORAGE MODEL FOR THERMIONICS POWER SYSTEMS
FUEL CELL DEVELOPMENT (US ARMY SIGNAL CORPS)	USES ION EXCHANGE REGENERATIVE PRINCIPLE
MHD FUNDAMENTAL RESEARCH (AFOSR)	PLASMA IONIZATION AND MATERIALS STUDIES
MHD ELECTRICAL ENERGY CONVERSION STUDY (WADD)	INVESTIGATION OF ALTERNATE CONCEPTS
MHD VEHICLE POWER CONSIDERATIONS (BMD)	ESTABLISHED FEASIBILITY OF MHD AS APU FOR MISSILES STUDIES FOR SPACE APPLICATIONS CONTINUING
SOLAR SIMULATION STUDY (AFCRC)	DEVELOP LIGHT SOURCE AND APPROPRIATE OPTICS TO SIMULATE SOLAR IRRADIANCE
TEMPERATURE CONTROL OF COLOR PHOTOVOLTAIC CELLS (WADD)	STUDY OF OPTIMAL USE OF SOLAR CELLS
50 WATT FUEL CELL TEST PROGRAM (WADD)	ZERO-G TESTS IN A/C AND NOSE CONES OF REGENERATIVE FUEL CELL
500 WATT AEROSPACE FUEL CELL CAPSULE (WADD)	DEVELOP A 500 WATT PRIMARY FUEL CELL BATTERY FOR ORBITAL TEST

Figure B-31. GE-MSVD space power experience

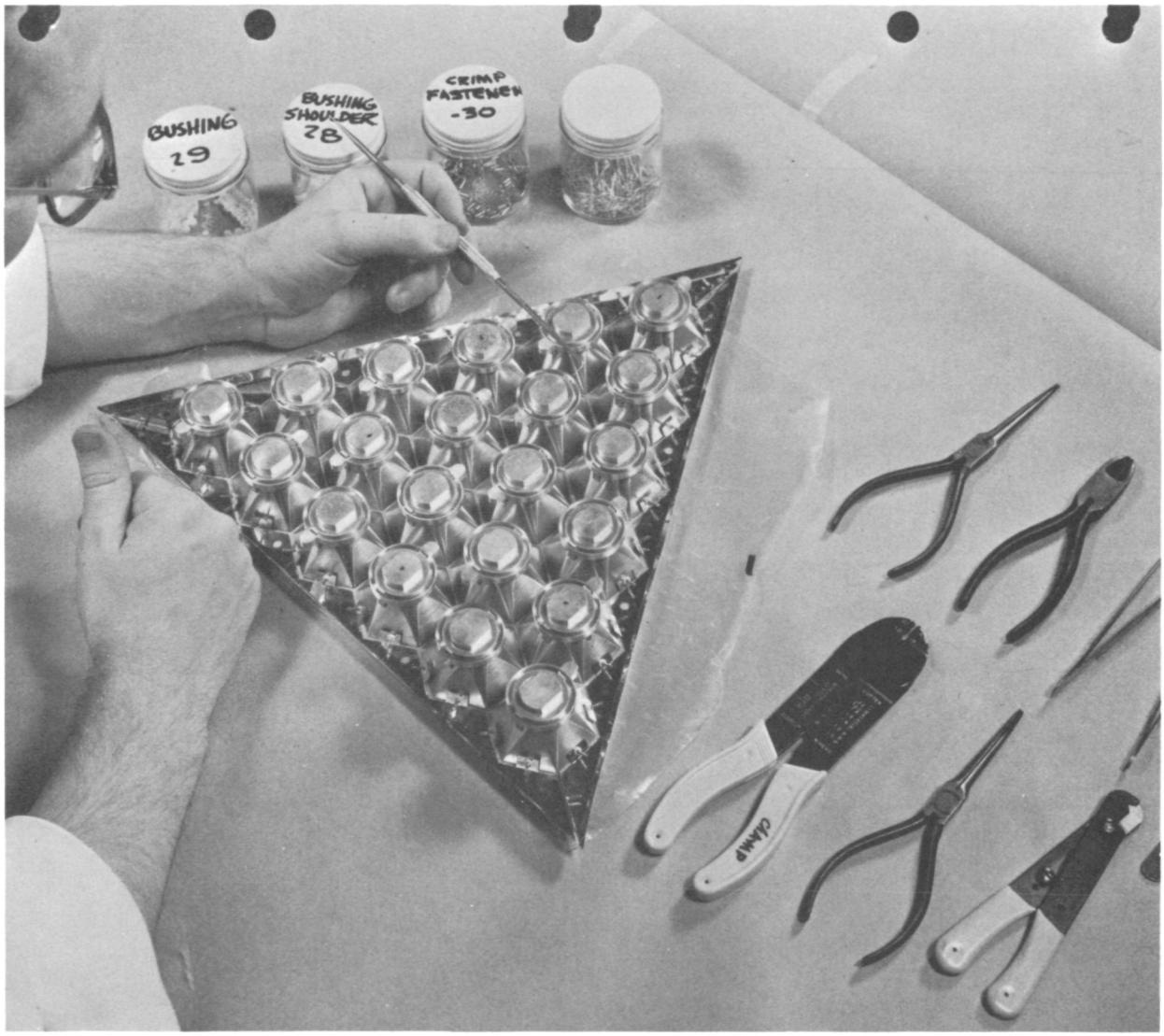


Figure B-32. Assembly of back cone segments of solar thermiome electrical power system

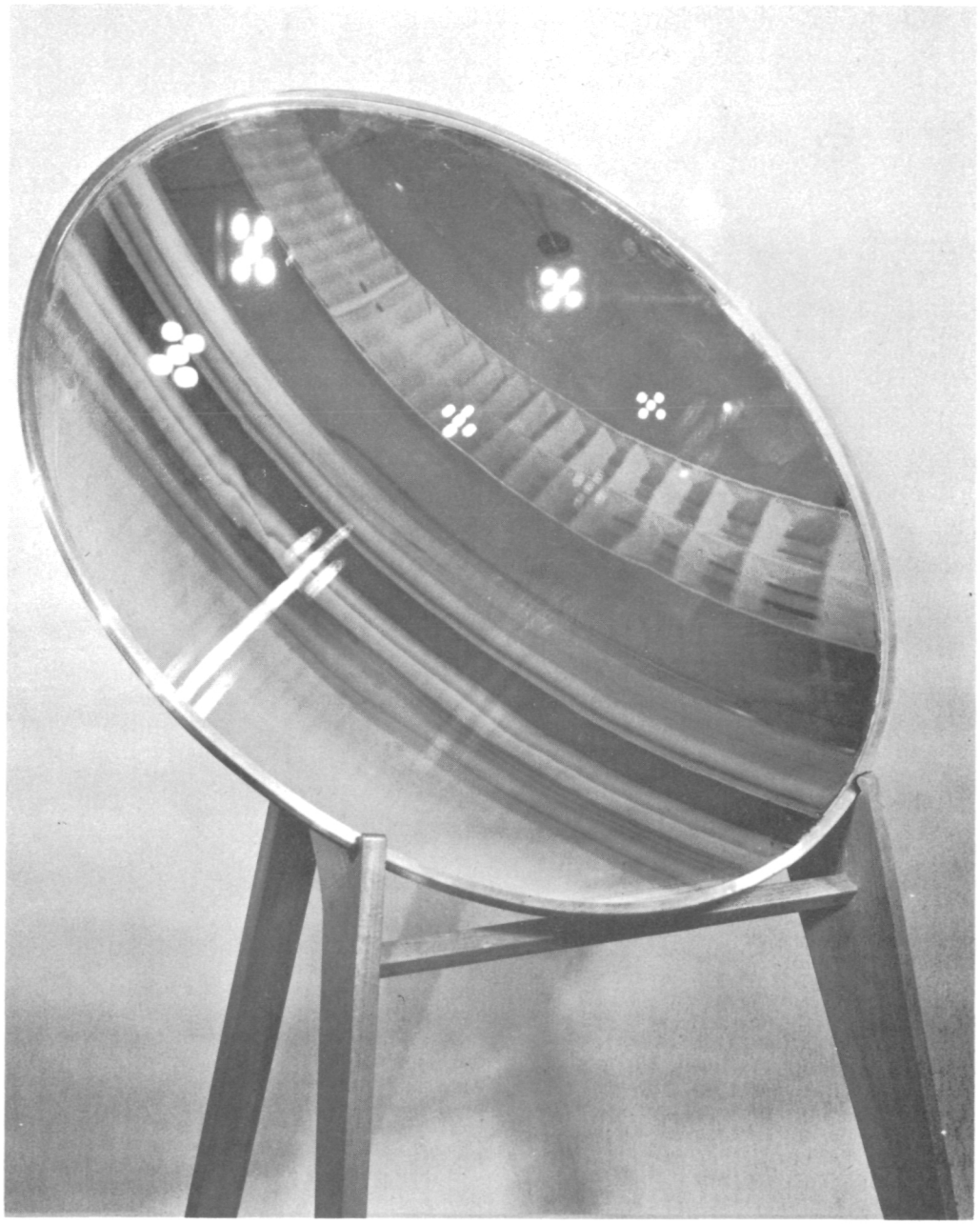


Figure B-33. MSVD developmental four-foot diameter solar collector

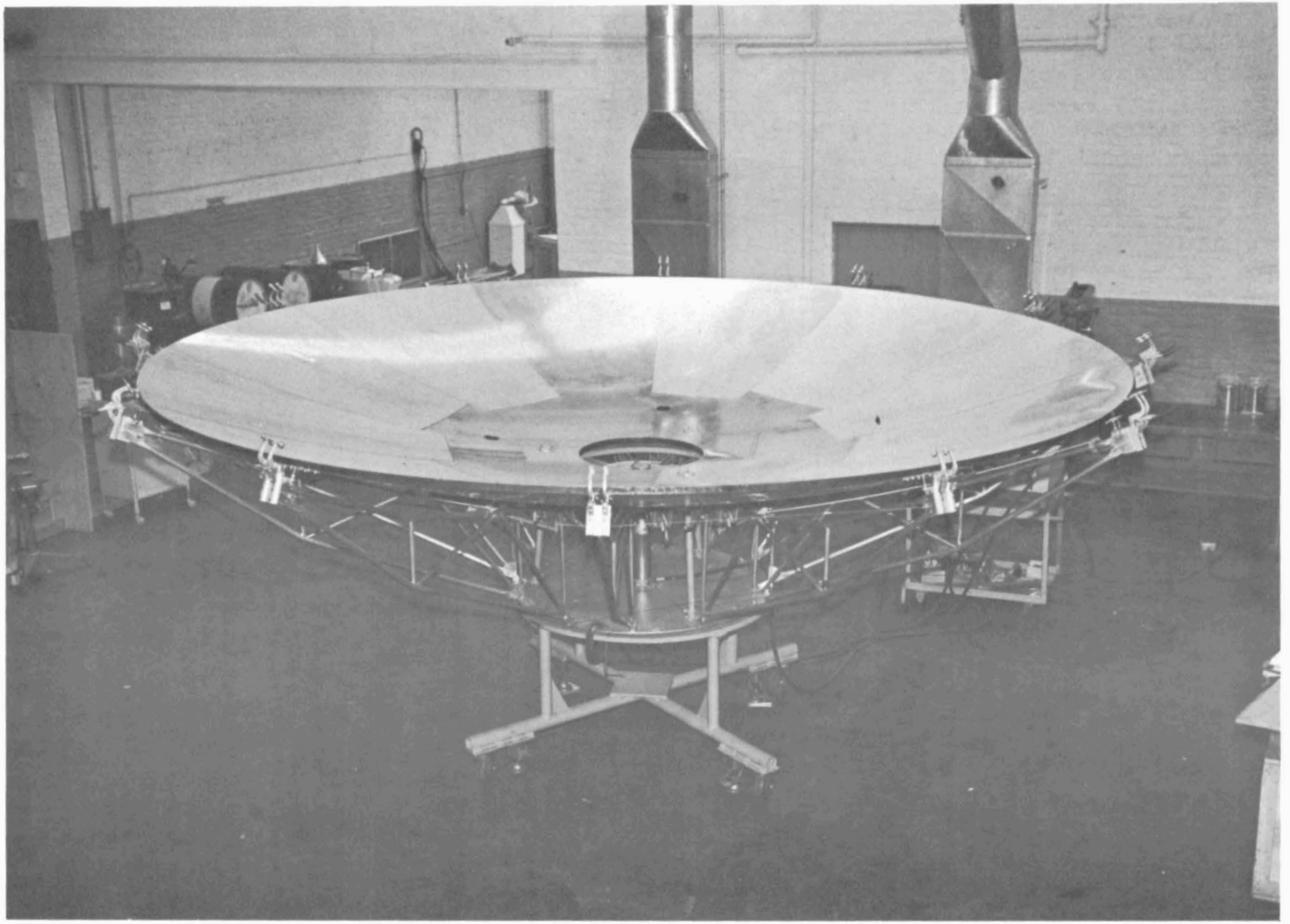


Figure B-34. Parabolic collector

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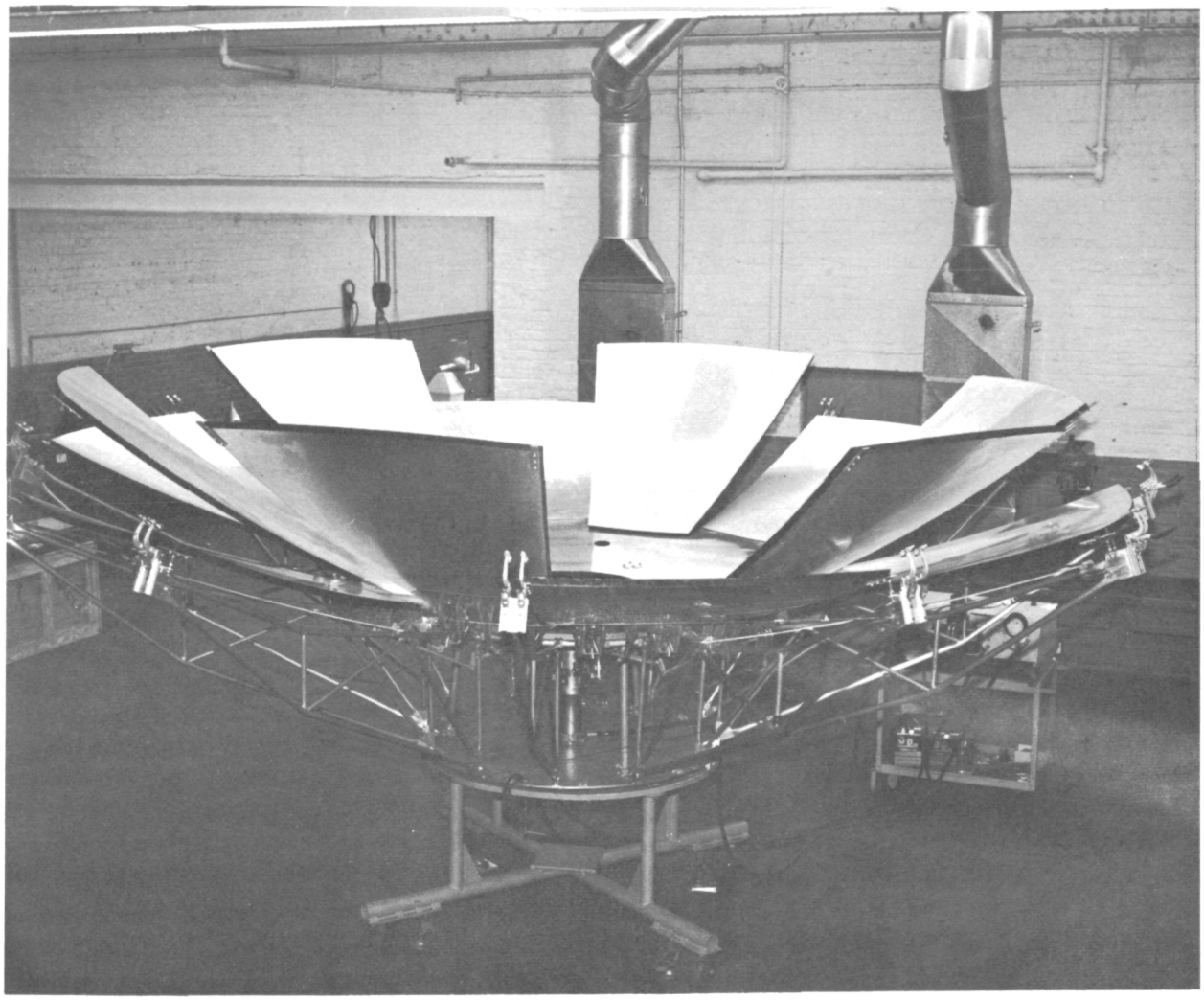

Figure B-35. Parabolic collector, semi-folded position

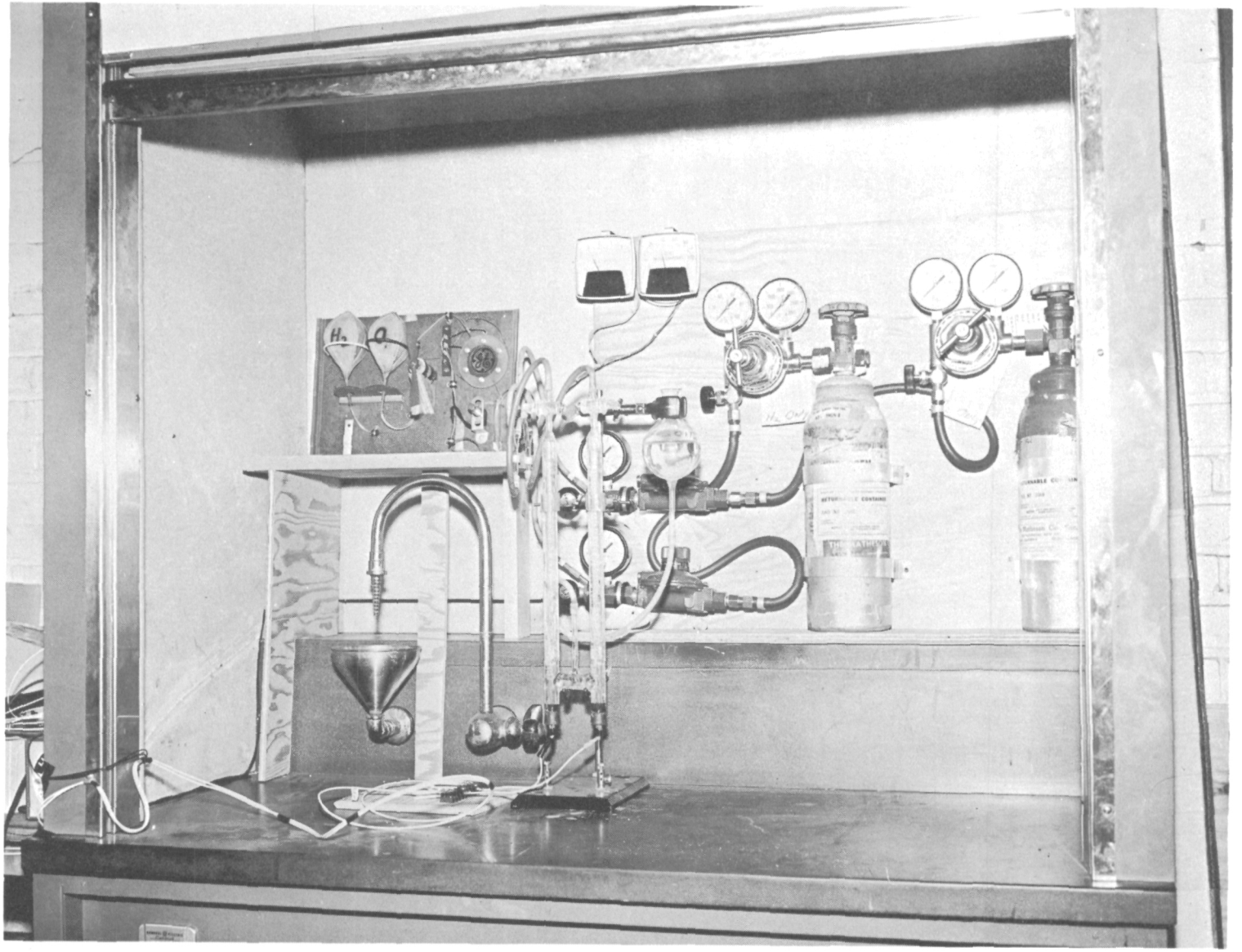

Figure B-36. Fuel cell closed system

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capability. Large power producing cells are being fabricated and tested, and engineering samples of multicell units are also being performance tested. Current plans also call for a re-entry vehicle flight test with a fuel-cell system to demonstrate zero-gravity and space-flight performance. This test is scheduled for the near future.

MSVD has a contract with the Army Signal Research and Development Laboratories for research and advanced development work to be performed in hydrogen-oxygen fuel cells. Work on this program will lead to a design for 500-watt regenerative fuel cells for space applications. Several small batteries of these ion-exchange membrane fuel cells will be available in a few months for evaluation.

1.2.6.5 SATELLITE POWER SYSTEMS

The Advent Satellite is powered by a photovoltaic-battery system. Silicon solar cells are mounted on two paddles extending from the main vehicle body. The solar arrays provide power directly to the vehicle electrical load and to nickel-cadmium storage batteries tied in parallel with the main bus. A power control unit serves the function of controlling solar array current in accordance with limitations imposed by the battery and the desire to maintain system voltage variation within certain limits.

A number of space power development programs are being carried out on the Advent contract. Pertinent ones are the following:

1.2.6.5.1 System Analog Study

In this program each subsystem of the power system is simulated in an analog computer. In addition, the primary system inputs and outputs, such as solar illumination and load, are simulated. The aim is to study optimum array and battery size to meet the system requirements. In the initial phase of this study, approximate models are used in the simulation. In later phases greater refinement of each

analog model will include such effects as cell degradation due to radiation damage, loss of optical transmittance in the solar cell cover glasses, the influence of temperature gradients on the solar array and temperature effects on the battery.

1.2.6.5.2 Digital Studies

This study has two main purposes: (1) optimization of the series — parallel interconnections required for the solar cells, and (2) determination of the overall array voltage — current characteristics. This latter effort will be accomplished by the reduction of data taken on large numbers of individual cells.

1.2.6.5.3 Power System Regulation

Various control circuits are being considered and developed for this purpose. This program is closely interlinked with the analog program previously mentioned.

1.2.6.5.4 Solar Array Simulator

As an important backup to the analog program, a device is being developed for simulating the characteristics of the solar array. This will be used in systems tests of the overall vehicle where simulation of the space environments required for the solar array may be extremely difficult to produce. The simulator will also serve as a sophisticated battery charger when used in conjunction with life testing of the battery.

1.2.7 Life Support Subsystem Experience

MSVD has studied, designed and fabricated various life support subsystems and complete ecological systems in conjunction with the various programs shown on Figure B-37.

1.2.7.1 DISCOVERER LIFE SUPPORT SYSTEMS

Figures B-38 through B-40 shows the mouse and primate life support systems designed, manufactured and tested for the Discoverer recoverable satellite. These systems contain an environmental control subsystem, regulated food supplies, an artificial atmosphere, and special instrumentation to measure and record the environment and animal reaction in flight. In all Discoverer flights the life support system functioned normally as planned.

Figure B-41 shows the life cell conditioner designed by MSVD for the Discoverer monkey life cell. It contains chemicals for removal of CO_2 and noxious gases with a blower to maintain air flow throughout the entire system.

1.2.7.2 CHIMPANZEE LIFE CELL

Figure B-42 shows an illustration of the Chimpanzee Life Cell designed, manufactured, and tested by MSVD for the Holloman Air Development Center to be employed for testing psychological reactions of the animals. The life cell has a 200 hour capability and is provided with separate controls for gas mixture, temperature, pressure and humidity.

Figure B-43 shows the completed chamber with the pneumatic controls and displays. Figure B-44 shows the CO_2 absorber and Figure B-45 shows the heat exchanger of the life cell. Figure B-46 shows the electrical control and display panel used with the chamber.

Orbiting Research Vehicles (USAF-BAD)	• Discoverer - Life cells have been developed and manufactured to support mice and small primates for a two day orbit. Designs have been completed for a 4-day mission
Vehicle Interior Configuration (NASA-STG; USAF-BMD & WADD) Collection, Disposal or Regeneration of Waste Products (NASA OLS; USN-ACEL)	• Design studies on APOLLO, Smart MTSS, GSS, Space Cabin, etc. • Research on collection and processing of biological wastes to obtain potable water • Demonstration of principle by engineered hardware to handle wastes of men for two weeks
Food Storage and Preservation (USAF-WADD)	• Frost - Food preservation hardware for a 3 man, 2 week mission
Generation of Compatible Thermal & Respiratory Environment (USAF-WADD & HADC)	• Cool - Thermal and humidity control hardware for a 3-man, 2 week mission • Closed environmental system for a large primate capable of 200 hour continuous operation
Extra Vehicular Protection (USAF-WADD)	• Space Cape - Design Study for an anthropomorphic "Space Suit"
Sensing and Data Display for Control Purposes	• MSVD sponsored studies for space rendezvous including operating console
Crew Station Facilities	• MSVD sponsored research and development resulting in patent disclosures on such items as space showers, space toilet, special sensors, etc.

Figure B-37. MSVD life support programs

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Figure B-38. Discoverer re-entry/recovery vehicle (left), animal life cell (in hand), and life-support system

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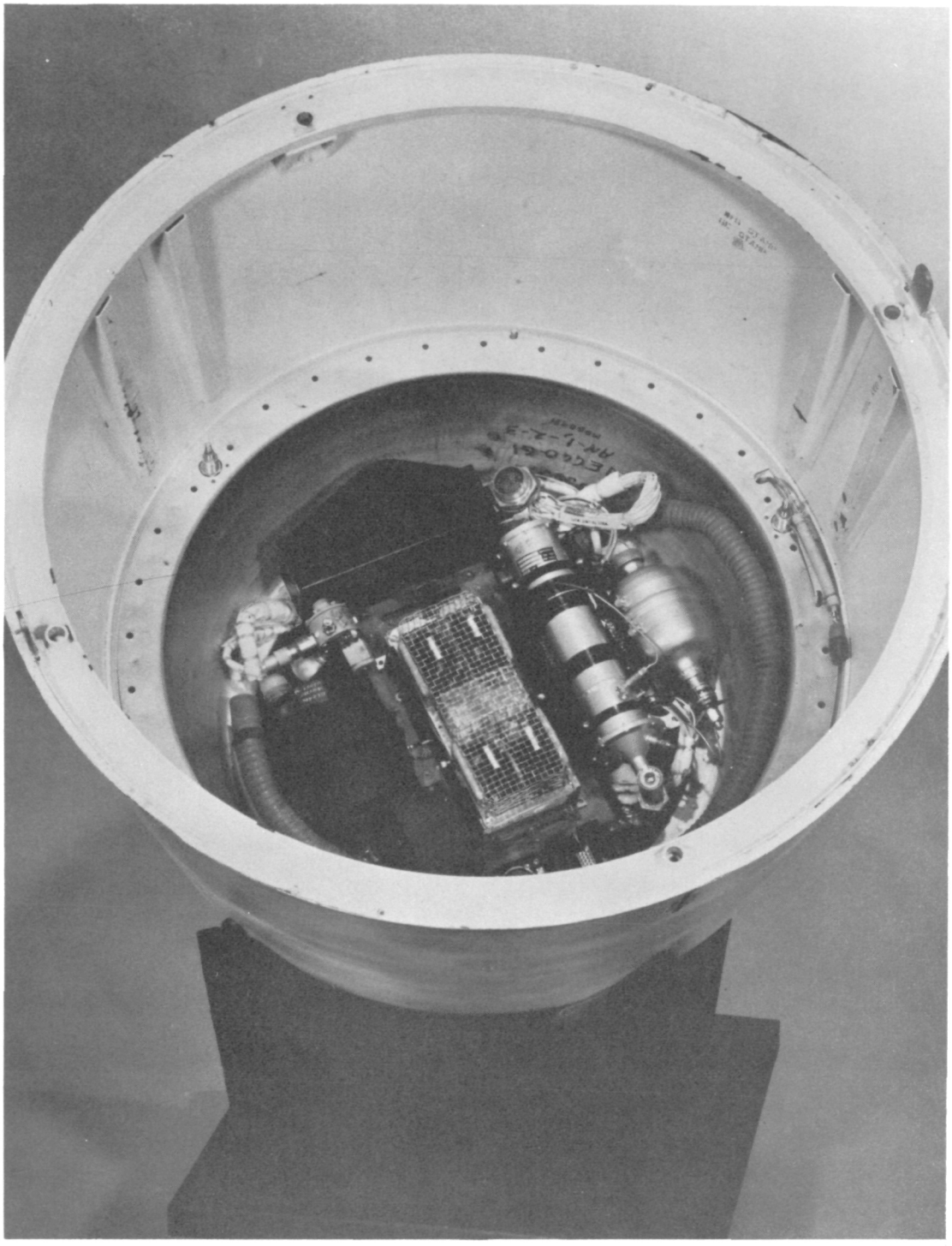

Figure B-39. Mouse life support system, Discoverer satellite

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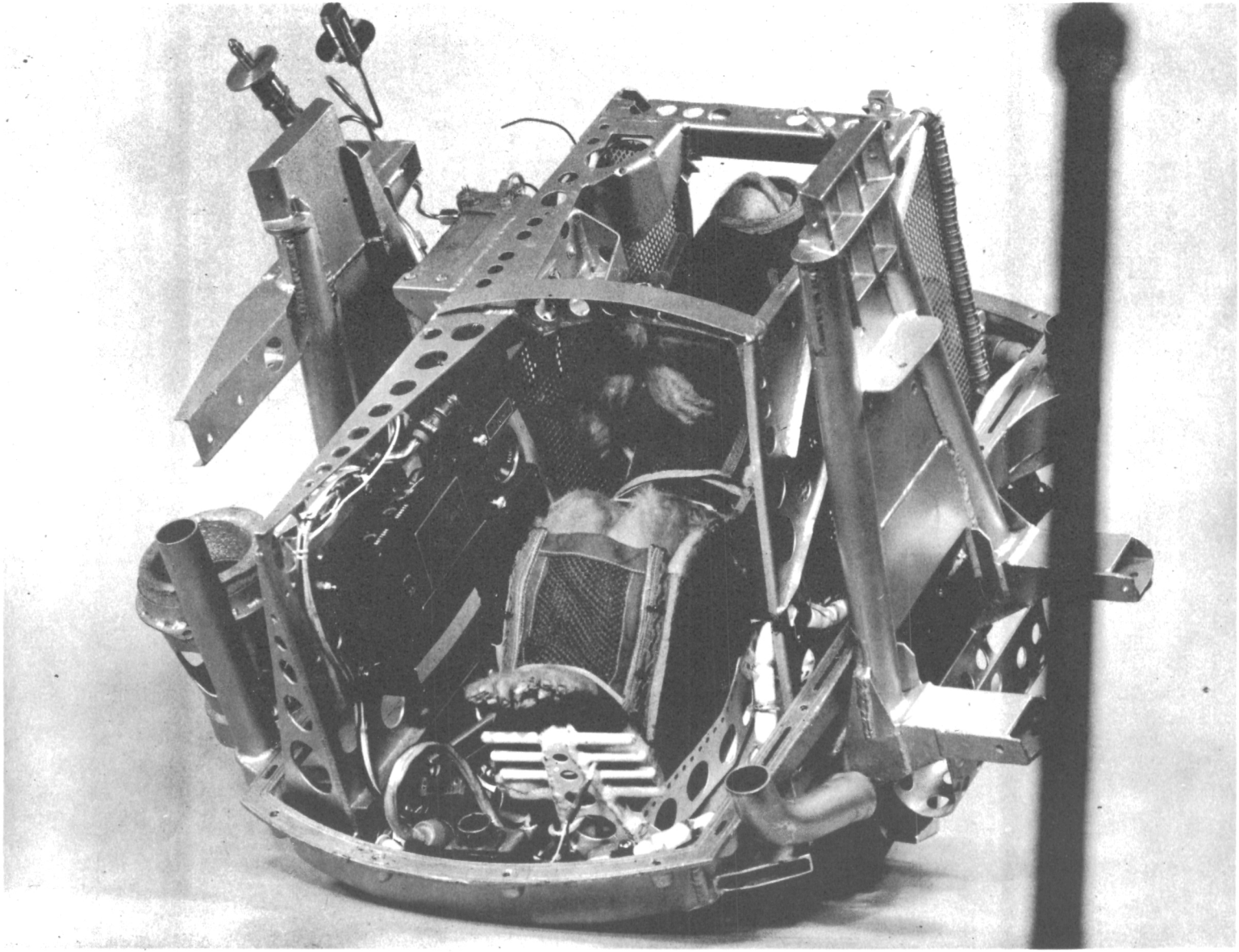

Figure B-40. Discoverer life support subsystem

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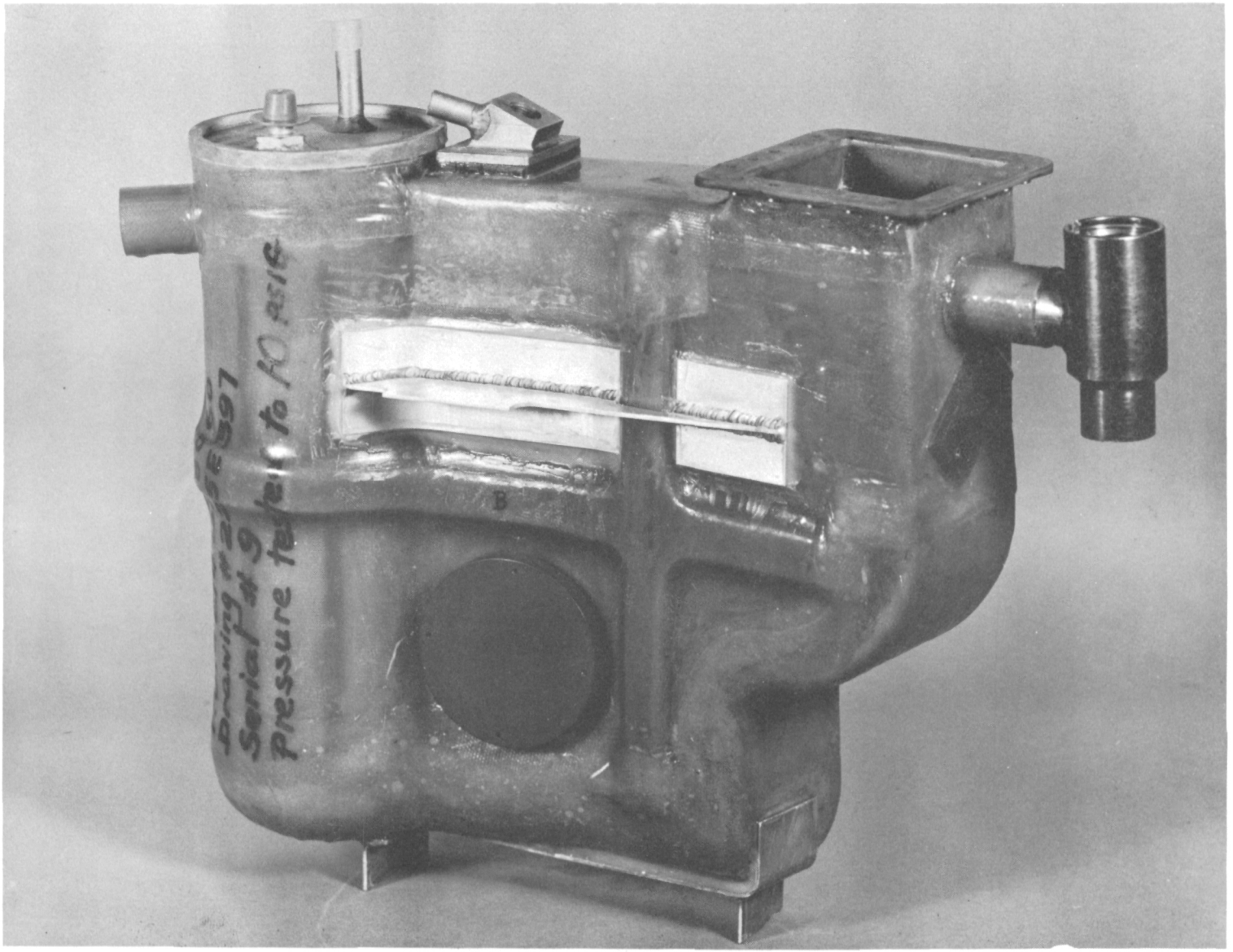

Figure B-41. Conditioner for Discoverer satellite - cooling and moisture and carbon dioxide removal

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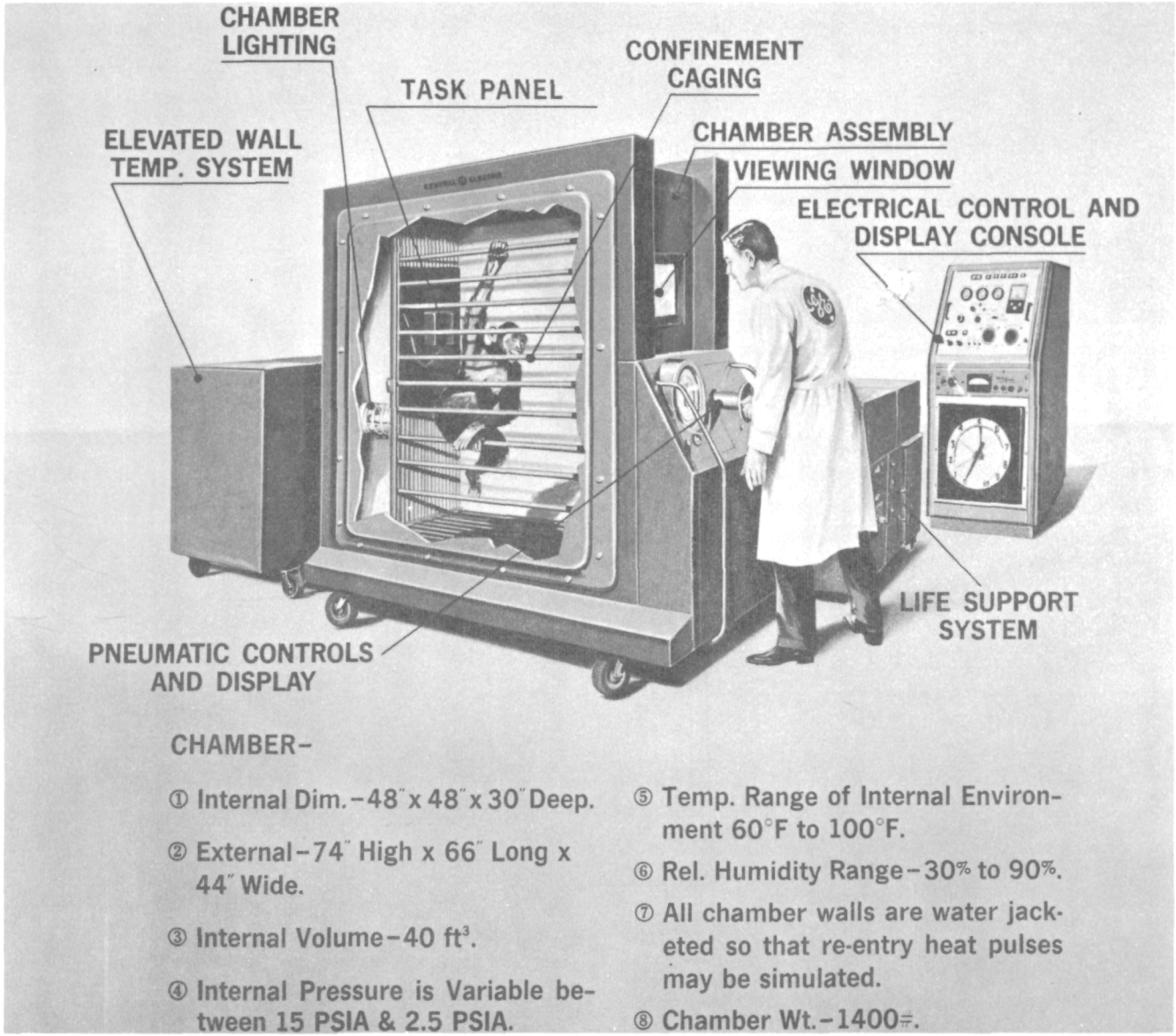

Figure B-42. Chimpanzee life cell

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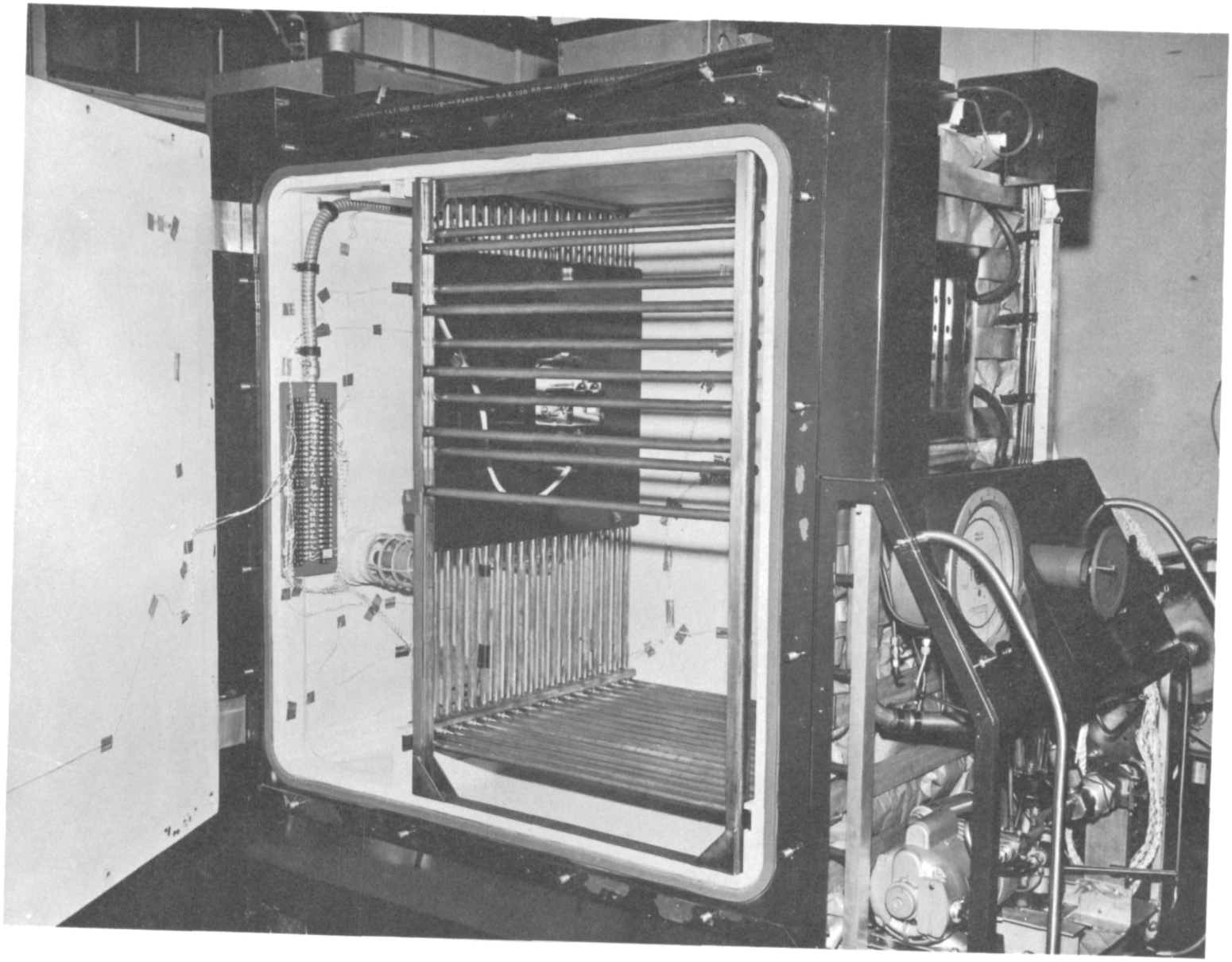

Figure B-43. Chamber and pneumatic controls of chimpanzee life cell

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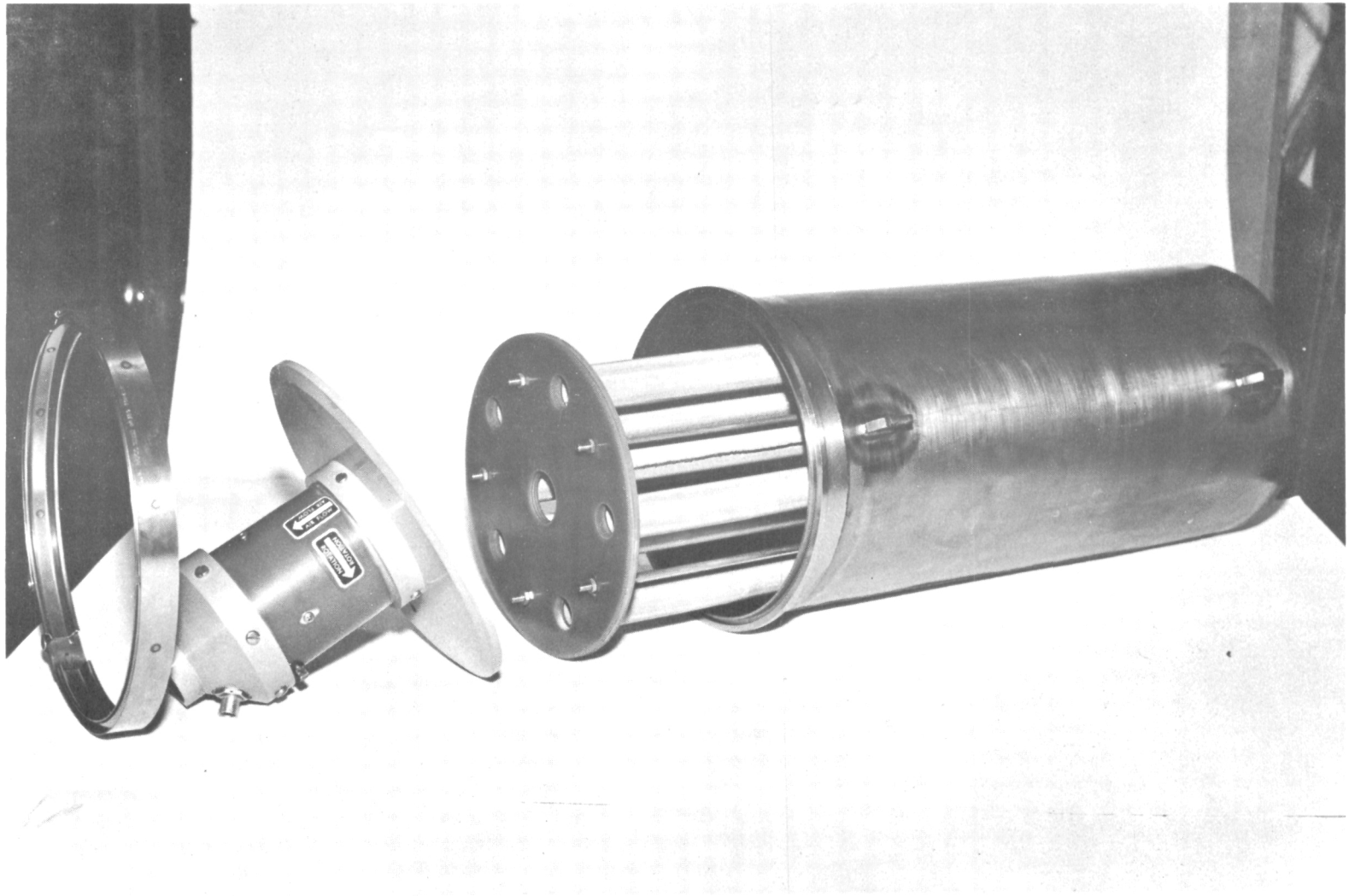

Figure B-44. CO_2 absorber of the chimpanzee life cell

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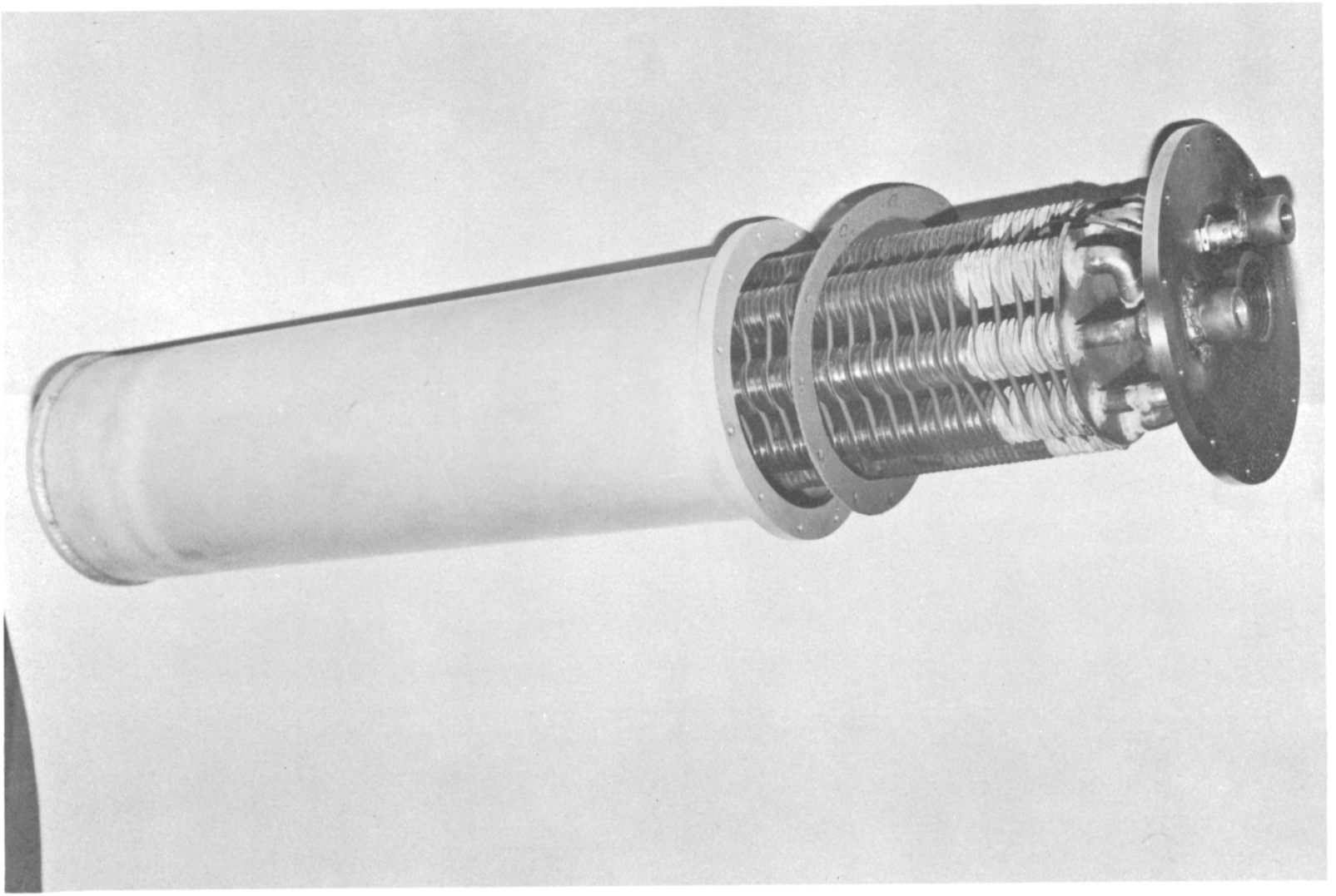

Figure B-45. Heat exchanger of the chimpanzee life cell

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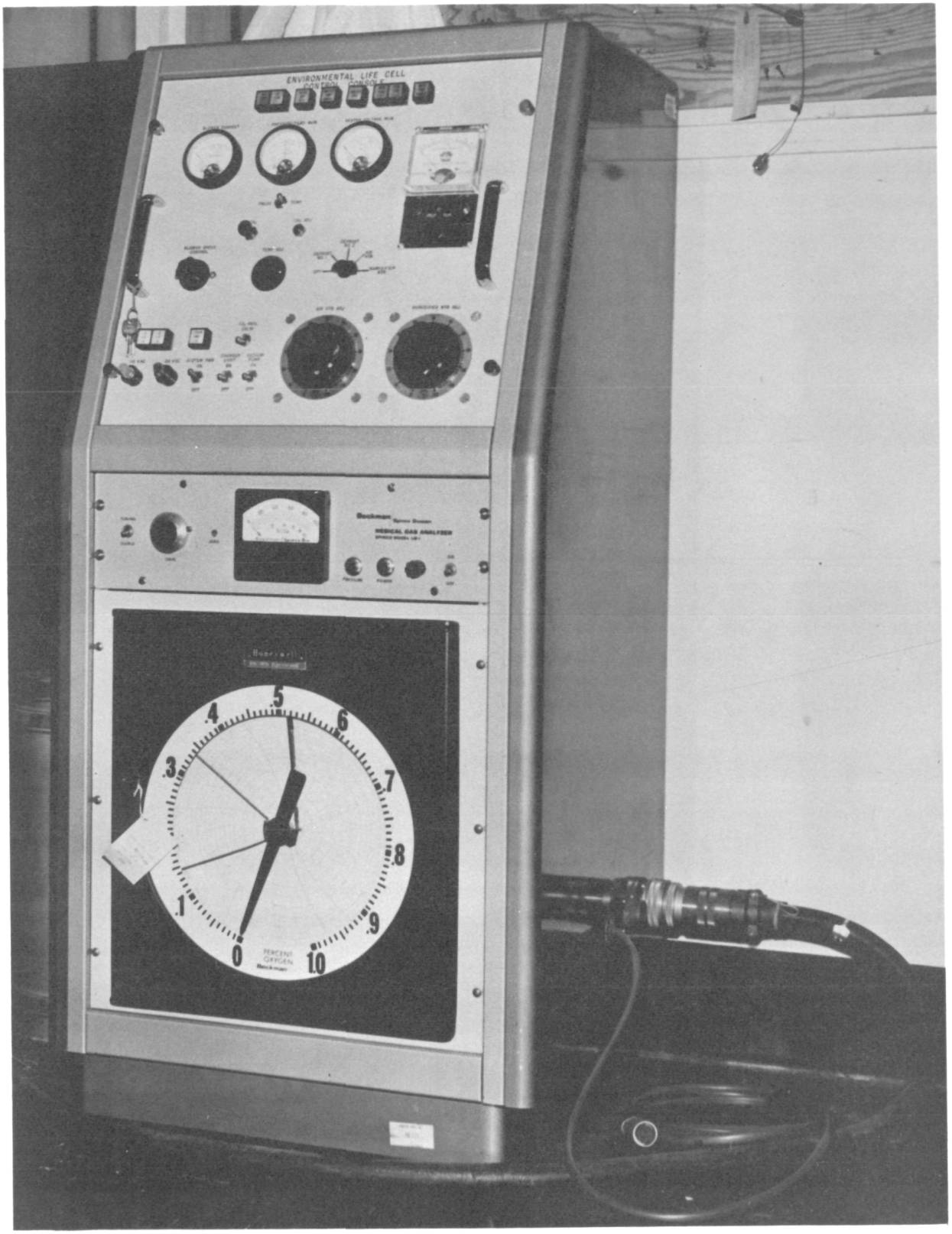


Figure B-46. Electrical control and display panel of the chimpanzee life cell

1.2.7.3 MANNED SPACE CABIN WORKING MODEL

On contract to WADD, MSVD designed and manufactured a full scale model of the space cabin shown in Figure B-47. The model contained working subsystems including a respiratory subsystem (Figure B-48), vehicle control, instrumentation and displays. Figure B-49 shows the acceleration seat being fitted to a space-suited crew member for the model and Figure B-50 shows an improved restraint seat designed by MSVD to protect man from acceleration and G-onset.

1.2.7.4 ADVANCED SYSTEM DESIGNS

MSVD has conducted the following advanced system designs for WADD which are directly applicable to APOLLO:

1.2.7.4.1 Cool Project

A feasibility study, design and fabrication of a combined food preservation and atmosphere maintenance system for a space craft cabin for missions of from 20 man days to 3 man years. Growth potential includes heating/cooling for all space craft now planned and extraterrestrial base systems using the liquid transport-radiator principle.

1.2.7.4.2 Space Cape Project

Establishment of performance requirements and preliminary design for an anthropomorphic space suit for space operations external to a space vehicle. Unique construction techniques are being developed and evaluated.

1.2.7.4.3 Frost Project

A study performed to establish an optimum refrigeration system for food storage and preservation. The results of this study led to the liquid transport approach used in the Cool Project.

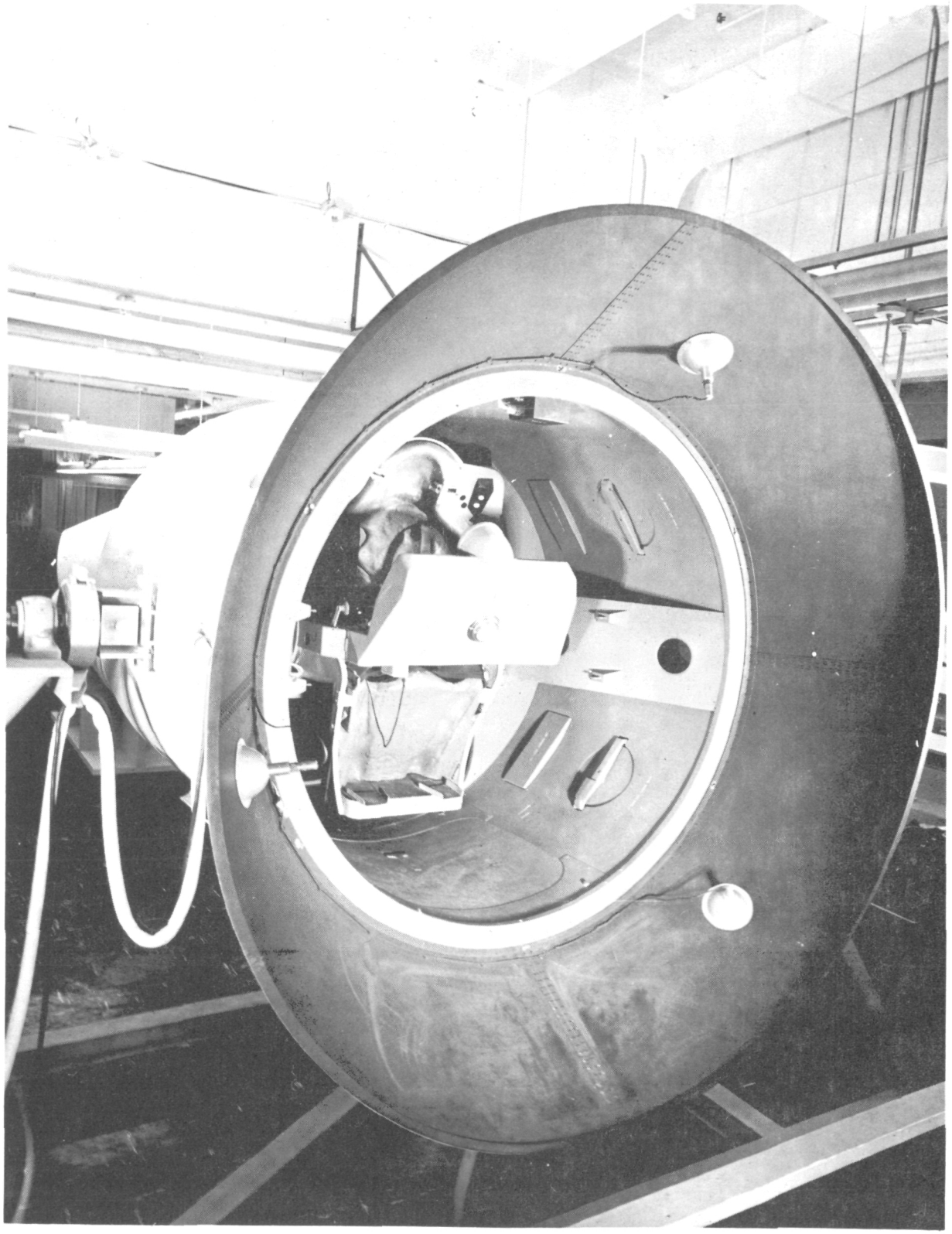


Figure B-47. One-man space cabin mock-up showing pilot's seat and control panel

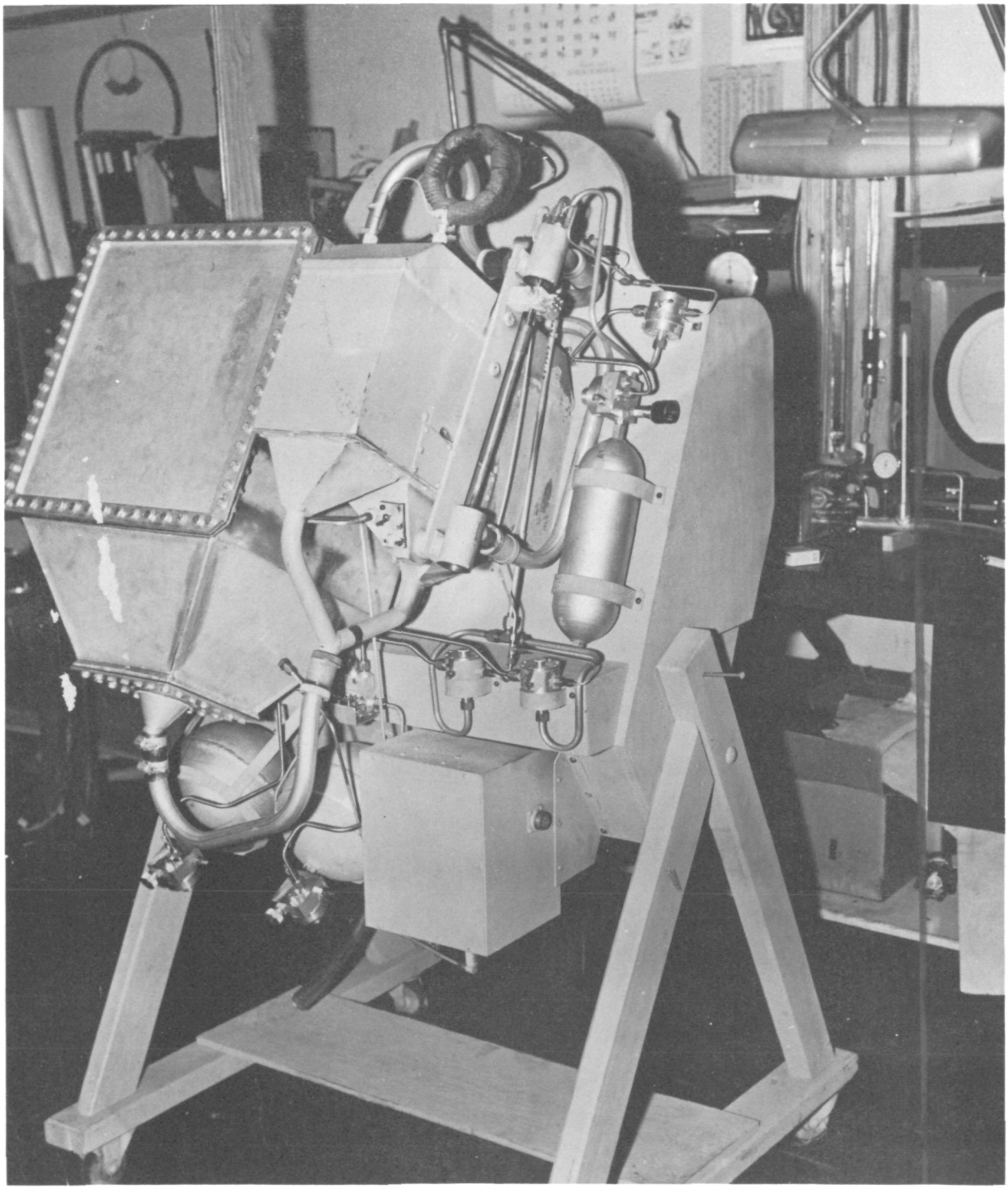


Figure B-48. Space cabin respiratory system

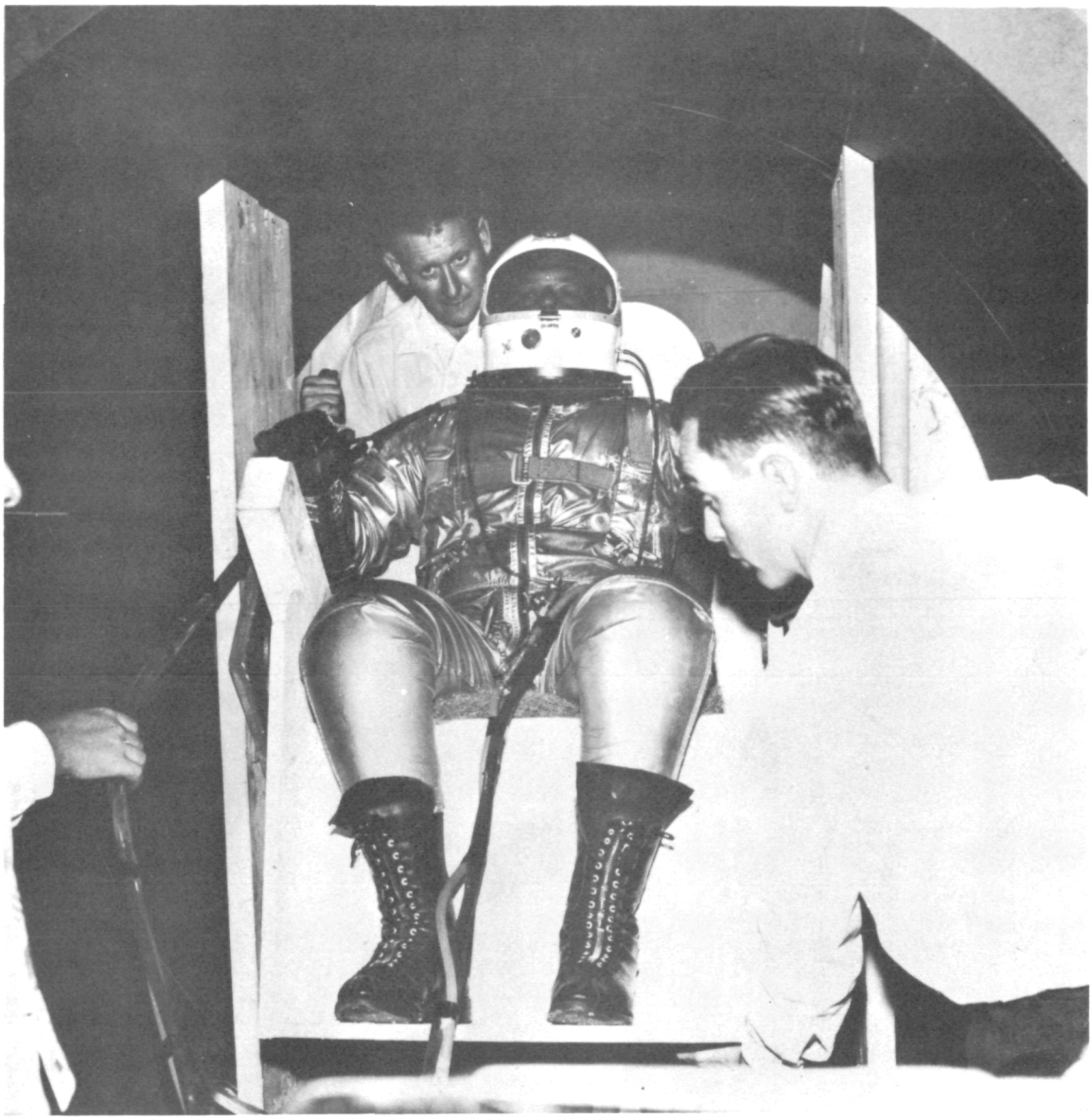


Figure B-49. Space-suited pilot being fitted for tailored space seat

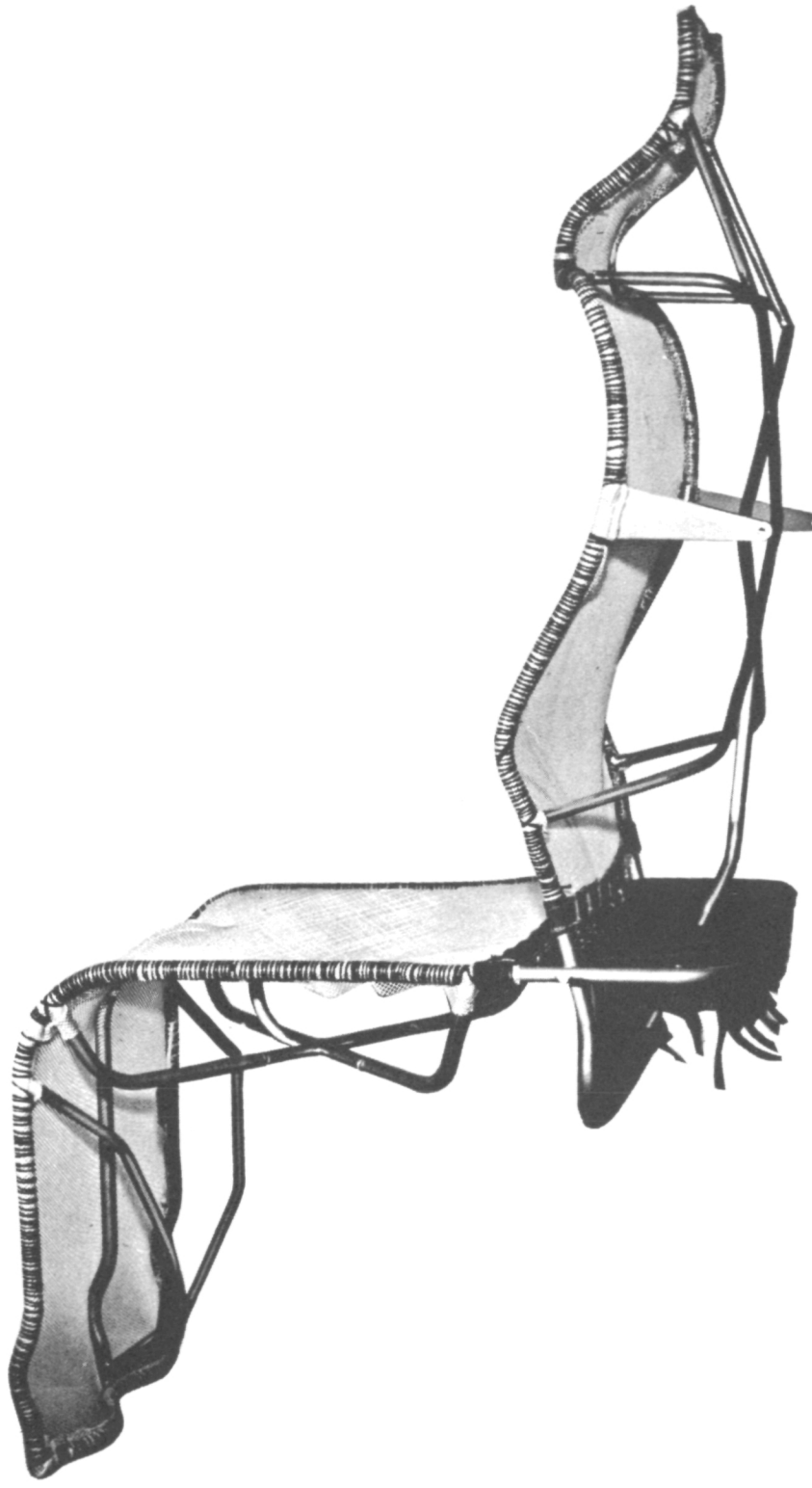


Figure B-50. Raschel net seat mock-up, side view

1.2.8 Search and Recovery Subsystem Experience

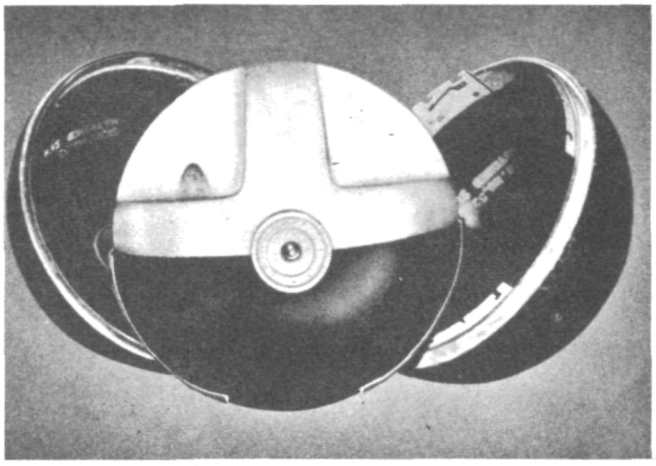
MSVD is one of the nation's most experienced organizations in the design and development of re-entry vehicles incorporating search and recovery aids and devices. Some of the MSVD accomplishments are:

- The Mark 2 data capsule was the first object ever recovered from space — June, 1958.
- The RVX-1 Re-entry/Recovery Vehicle was the first vehicle ever to be recovered after an ICBM flight — April, 1959.
- The Mark 2 data capsule was recovered with the first motion pictures of earth taken from a vehicle travelling in outer space — May, 1959.
- The RVX-2 Re-entry/Recovery Vehicle was the largest vehicle ever to be recovered in the Free World — July, 1959.
- The Discoverer Re-entry/Recovery Vehicle was the first object ever recovered from orbit — August, 1960.
- The Nuclear Emulsion Recovery Vehicle was the object recovered from the highest altitude — September, 1960.

1.2.8.1 DATA CAPSULE RECOVERY EXPERIENCE

For heat sink type re-entry vehicles such as the Mark 2, where recovery of the vehicle itself is not necessary, a GE-designed data capsule was employed. Figure B-51.

The data capsule is a sixteen-inch diameter sphere made of a foamed plastic material designed to absorb shock and permit the capsule to float on water. The primary payload of the data capsule is a tape recorder. However, the capsule also contains locating devices such as an electronic beacon, two flashing strobe lights, a SOFAR bomb, and aluminum powder to provide a dye slick on the surface of the water.



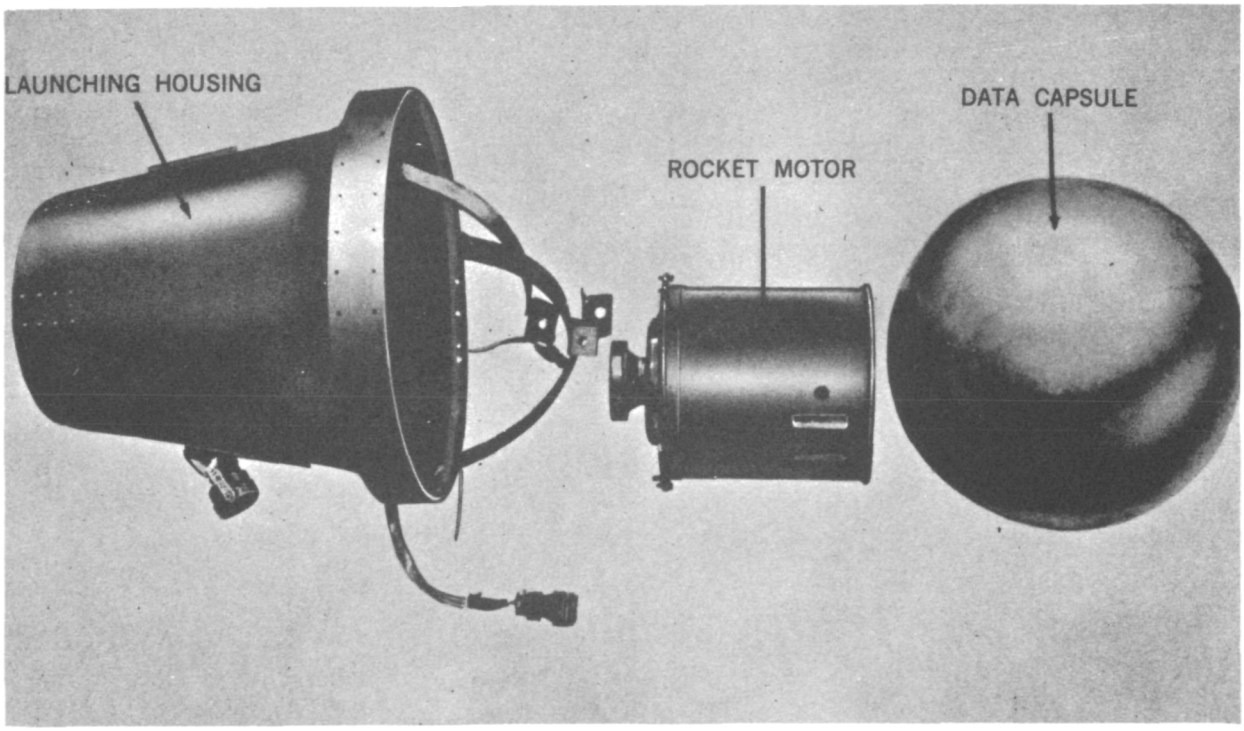


Figure B-51. Mark 2 data capsule

In some of the experiments, the SOFAR bomb was removed and a camera was put in its place. Other scientific experiments were conducted which replace both the SOFAR bomb and the tape recorder, thus providing a payload capacity for scientific equipment of approximately 300 cubic inches which carried up to sixteen pounds of weight.

The data capsule is programmed to be ejected during flight. At the selected point in the trajectory, the cover is blown off and the capsule is ejected. After the capsule and the ejection assembly are separated, a drogue drag device is released which insures that the capsule will land properly. At impact, the outer shells are shattered and are separated from the recoverable capsule. Because of the high impact loads that are felt by the capsule (approximately 40,000 G), special components had to be developed capable of withstanding these loads.

The following numbers of tests conducted by MSVD on data capsule development show the depth of experience possessed in recovery disciplines:

Number of Tests		Type of Test
305	—	Component Qualification Tests
32	—	Wind Tunnel Tests
		15 — Spin Tests
		10 — Drogue Snatch Loads
		4 — Stability
		3 -- Dynamic Damping
25	—	Firing Range Tests
6	—	Flotation Tests
17	—	Water Impact Tests
17	—	Ground Ejection Tests
70	—	Aircraft Drop Tests
19	—	Flight Tests

1.2.8.2 SPACE VEHICLE RECOVERY EXPERIENCE

In order to investigate comprehensively the ablation phenomena during flight test, a three step research flight test program was established at MSVD by the USAF, using three different but related types of recoverable re-entry vehicles. The experience gained by MSVD in the pursuit of these programs is directly related to the APOLLO program. The vehicles, Able Phase 0, RVX-1, and RVX-2, utilized a parachute recovery system with balloon flotation and recovery aids.

A brief description of the sequence of operation for RVX-1 recovery follows (see Figures B-52 and B-53). During re-entry, a programmer triggered by an acceleration switch starts the sequence of operation. The first event is ejection of the heat protection cover. This is followed by deployment of the parachute at supersonic speeds of approximately Mach 1.2. After the parachute is fully inflated, it pulls the recovery package basket out of the re-entry/recovery vehicle to permit inflation of the flotation balloon.

Simultaneously, a SOFAR bomb and a chaff package are released as aids to recovery. When the balloon is fully inflated, the tethering lines which hold the balloon to the basket are cut permitting the balloon to float above the parachute. Upon contact with water, a sea-water switch activates a Sarah beacon and a flashing strobe light as further aids to recovery.

The scope of development background necessary to adequately qualify the recovery system is shown below. The more significant of these tests are the systems-type tests involving complete hardware. Flotation set-out tests were conducted in various sea-state conditions and supersonic aircraft drop tests were conducted in order to simulate as closely as possible actual flight environment. In addition, six missile flight tests were conducted. On four flights the re-entry vehicle was put into trajectory; all four vehicles re-entered successfully, and two were recovered.

120	—	Component & Systems Qualification Tests
13	—	Wind Tunnel Balloon Tests

16	—	Wind Tunnel Parachute Tests
16	—	Wind Tunnel Cover Tests
37	—	Cover Static Firing Tests
4	—	Flotation Tests
5	—	Supersonic Aircraft Drop Tests
6	—	Flight Tests

The sequence of operation for the recovery system of the RVX-2 (Figure B-54) is similar to that of the RVX-1; however, because the RVX-2 is much larger and the $W/C_D A$ is greater than the RVX-1, the first stage of the parachute is deployed in a reefed condition at subsonic speeds of approximately Mach 0.8.

After the parachute is disreefed and is fully inflated, the remaining sequence of events are the same as those for the RVX-1.

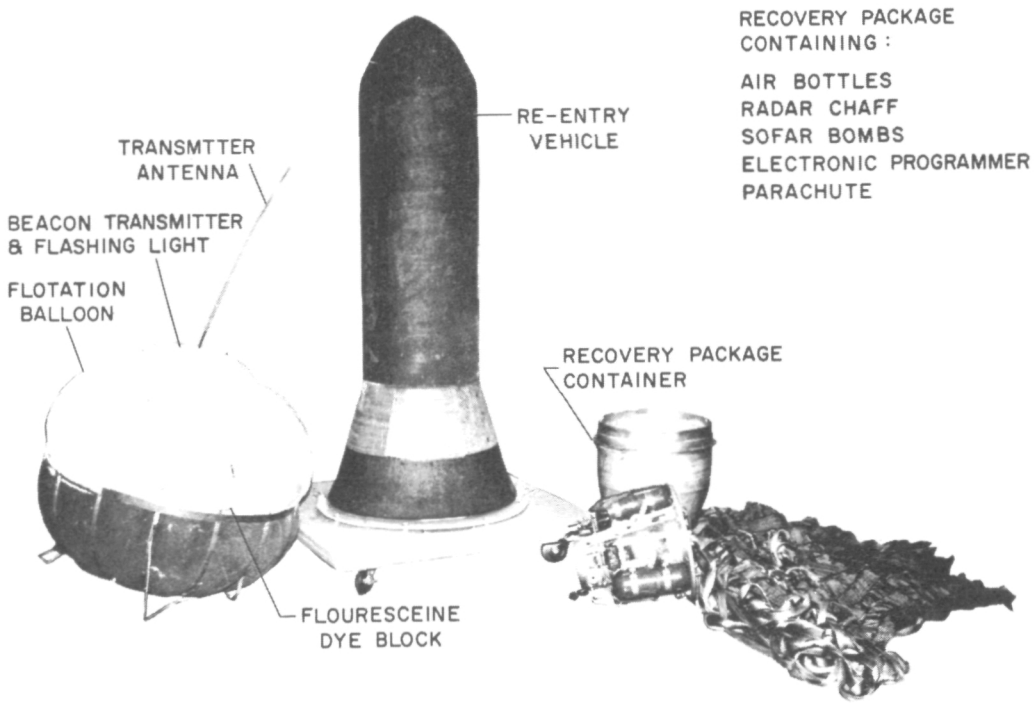


Figure B-52. RVX-1 after recovery, with search and recovery equipment

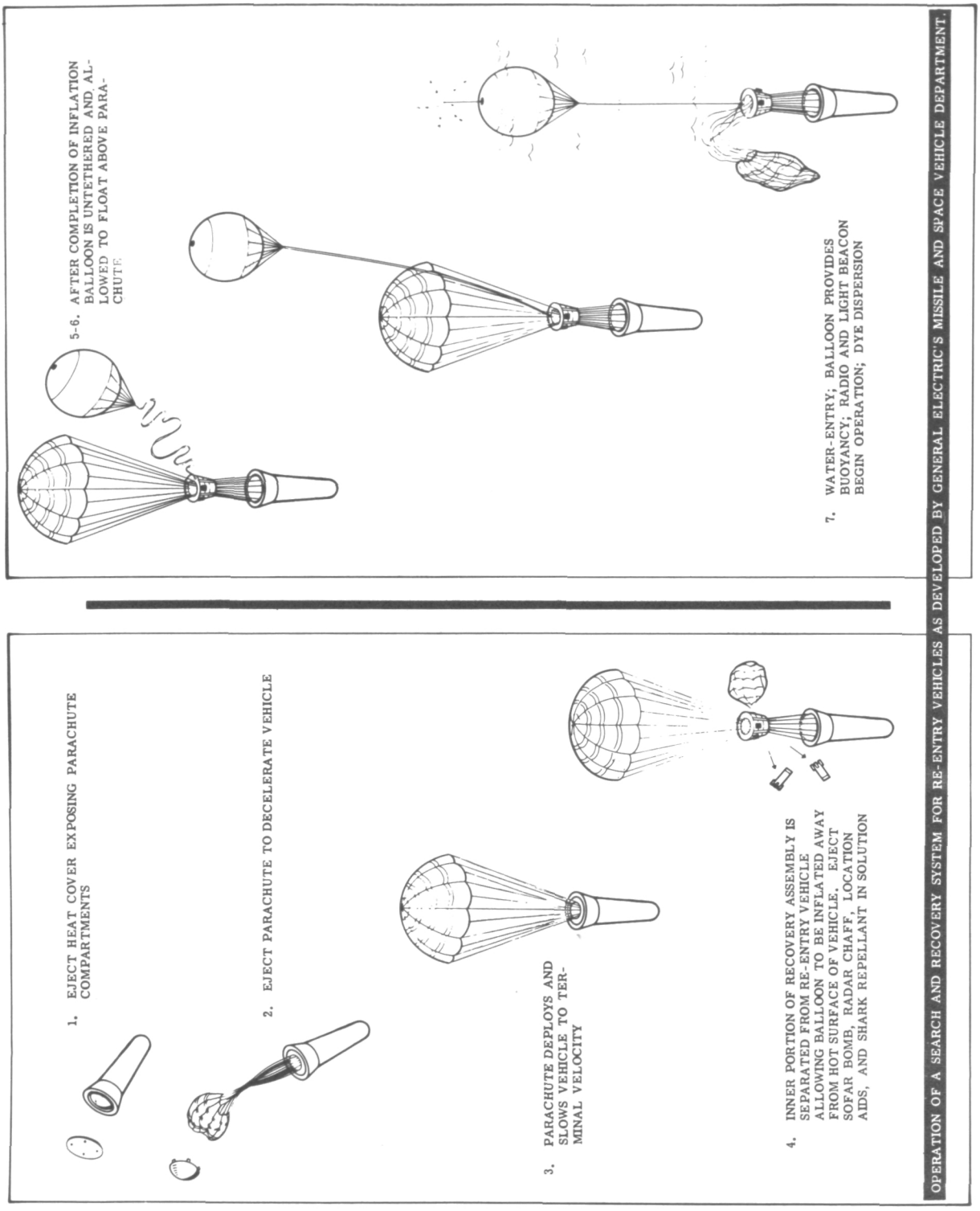


Figure B-53. Recovery sequence, RVX-1

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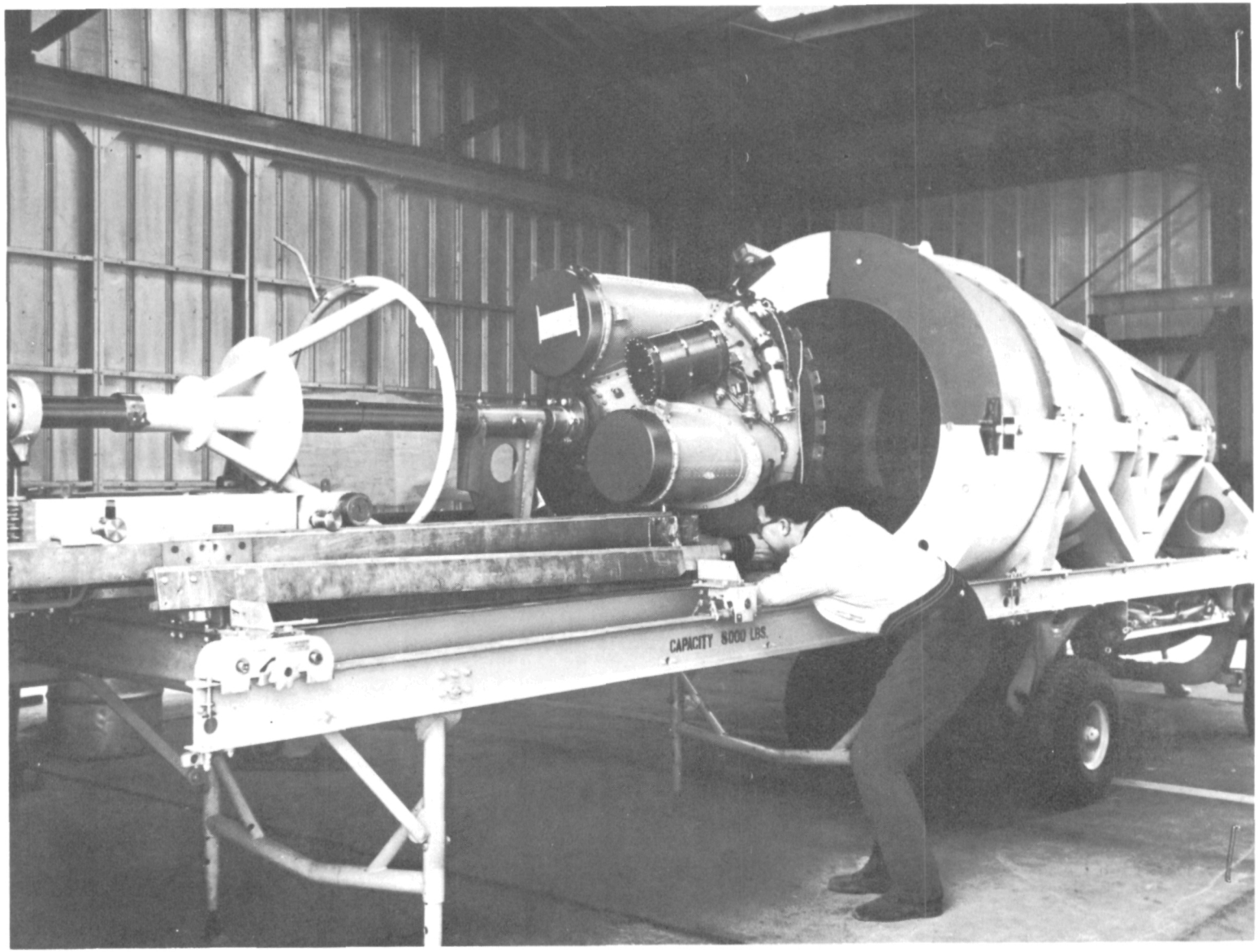

Figure B-54. Installing recovery package in RVX-2

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The RVX-2 development program follows the same pattern and utilizes much of the experience gained from the RVX-1. The various tests which were run were as follows:

75	—	Component and System Qualification Tests
16	—	Wind Tunnel Balloon Tests
12	—	Wind Tunnel Cover Tests
21	—	Cover Static Firing Tests
3	—	Flotation Tests
3	—	Aircraft Drop Tests
3	—	Flight Tests

1.2.8.3 SATELLITE RECOVERY EXPERIENCE

MSVD's experience in designing the Satellite Recovery Vehicle (SRV) for the Discoverer Satellite Program is directly applicable to several of the technical areas of APOLLO. The SRV is a re-entry vehicle designed to return a payload safely from an orbiting satellite. The critical problems of ejection from the satellite, vehicle stabilization and attitude control, and heat protection throughout a relatively prolonged re-entry flight have been sucessfully mastered in the SRV design. The duration of the SRV re-entry flight is considerably longer than that of any existing ballistic missile re-entry vehicle flight and consequently, imposed severe conditions on the design of a heat protection system. The re-entry heat protection shield developed for the SRV is an important advance in the state-of-the-art. The knowledge gained from the SRV program should greatly benefit MSVD's handling of the APOLLO Program. The following shows the extent of the testing accomplished on the Discoverer recovery subsystem:

162	—	Component and Systems Development Tests
30	—	Wind Tunnel Backward Stability
10	—	Wind Tunnel Aero. Coefficients
29	—	Firing Range Tests

1	—	Sled Test
2	—	System Tests Static
6	—	System Load Tests
17	—	Aircraft Drop Tests
15	—	Flights

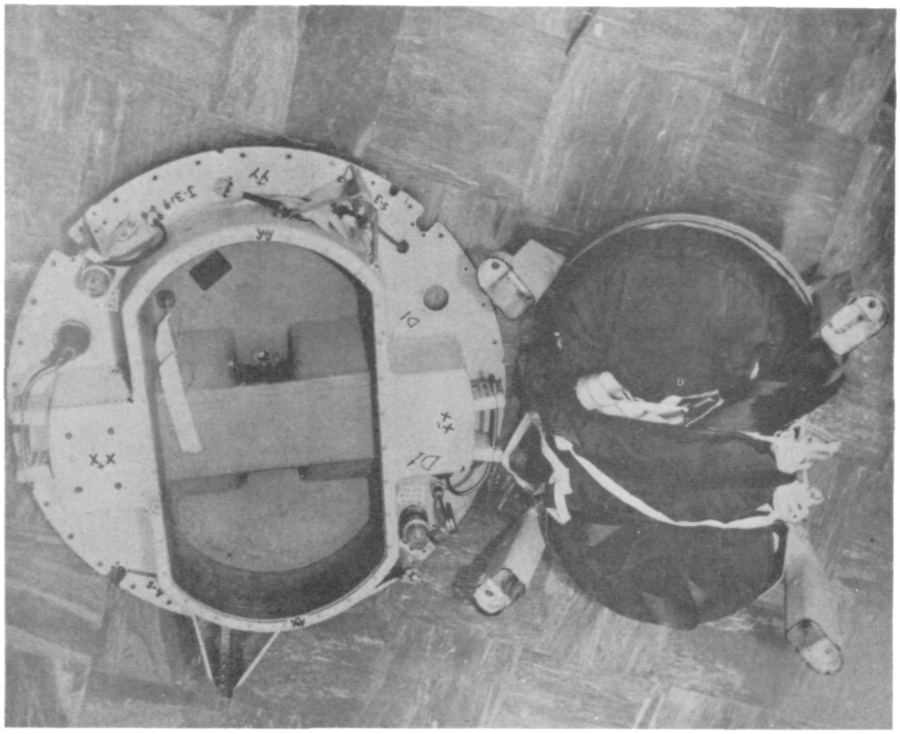
Figure B-55 shows the Discoverer recovery system which was employed to successfully recover Discoverer XIII from earth orbit. Figure B-56 shows the recovery sequence including the air snatch.

1.2.9 Ground and Space Support Equipment Experience

The Missile and Space Vehicle Department has developed, designed, produced, installed, and operated ground support equipment for both experimental and operational re-entry and space vehicles. This equipment has been delivered on schedule and has operated reliably, as evidenced by the fact that MSVD equipment has never cancelled an AMR flight.

Ground support equipment for the Atlas and Thor re-entry vehicles has been designed and developed to meet Strategic Air Command concepts and requirements. Indicative of the simplified and integrated approach taken by MSVD is the direct interchangeability of ground equipment between the Thor and Atlas re-entry vehicle programs. Also, the Mark 3 GSE is interchangeable between the Atlas and Titan missiles.

The complete system synthesis of MSVD ground support equipment and AEC-Sandia warhead equipment is a matter of record. This equipment successfully passed design engineering inspections on both missile systems. In addition, integration of ground support equipment with facilities and installations requirements has been completed for both ZI and foreign bases. The utility of this equipment in operation has been demonstrated through the accepted performance of inherent unit proficiency system capability. Both R and D and production experience with this equipment has been gained in IRBM and ICBM programs.



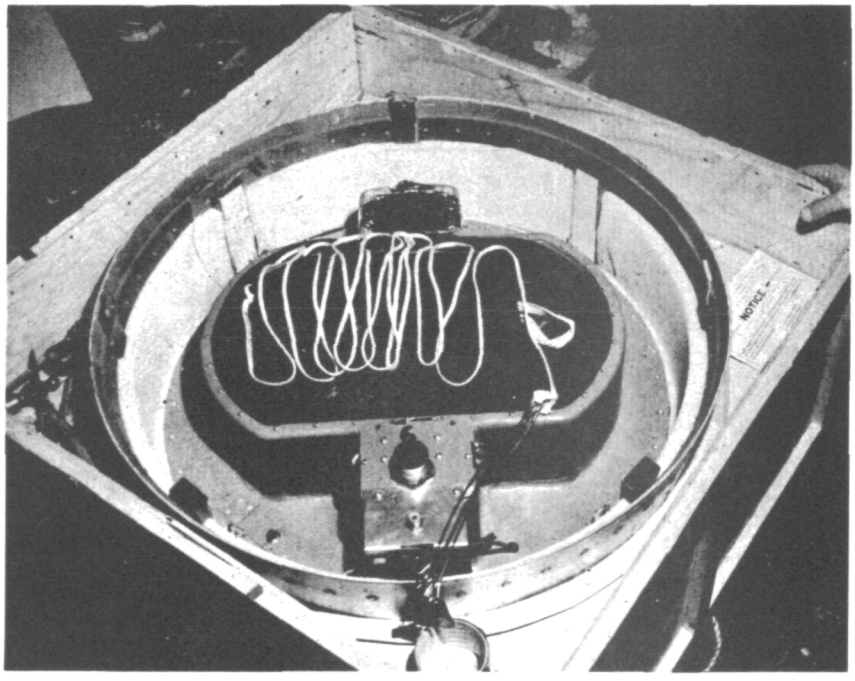


Figure B-55. Discoverer XIII recovery subsystem

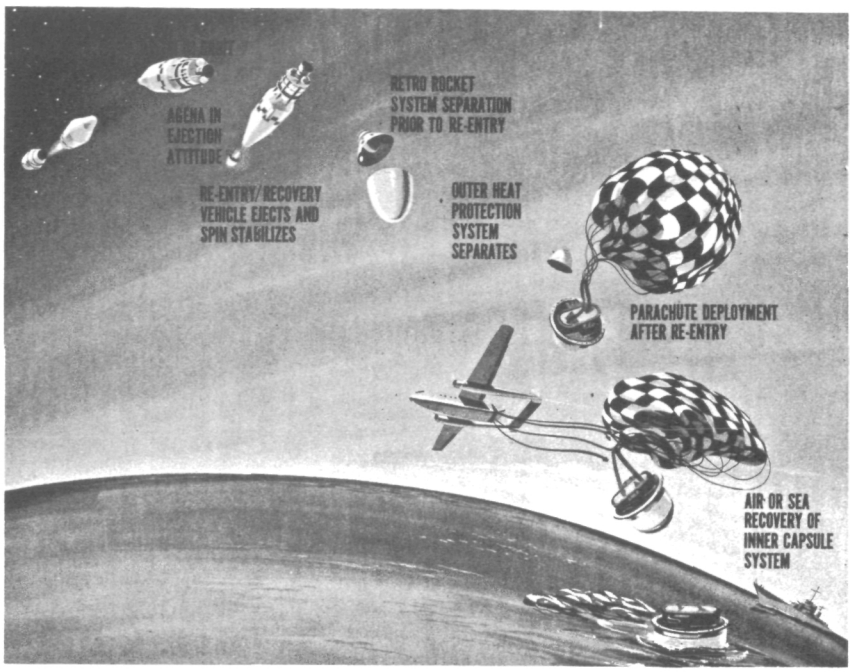


Figure B-56. Discoverer re-entry/recovery sequence

The utility and reliability of MSVD ground support equipment have been demonstrated in field support of actual production re-entry vehicles. This equipment is suitable for use over a broad range of climatic environments. Within the Thor and Atlas programs, a very rapid transition from the research and development phase to full production capability has been effected.

The following are some representative examples of the support equipment produced for other programs:

1. DISCOVERER Satellite vehicle test console, Figure B-57, was used for system tests at General Electric, Lockheed (System Contractor), and pre-launch checkout at Vandenberg Air Force Base.

2. THOR/ATLAS production model re-entry vehicle console, Figures B-58 and B-59, combines assembly and test checkout and launch site

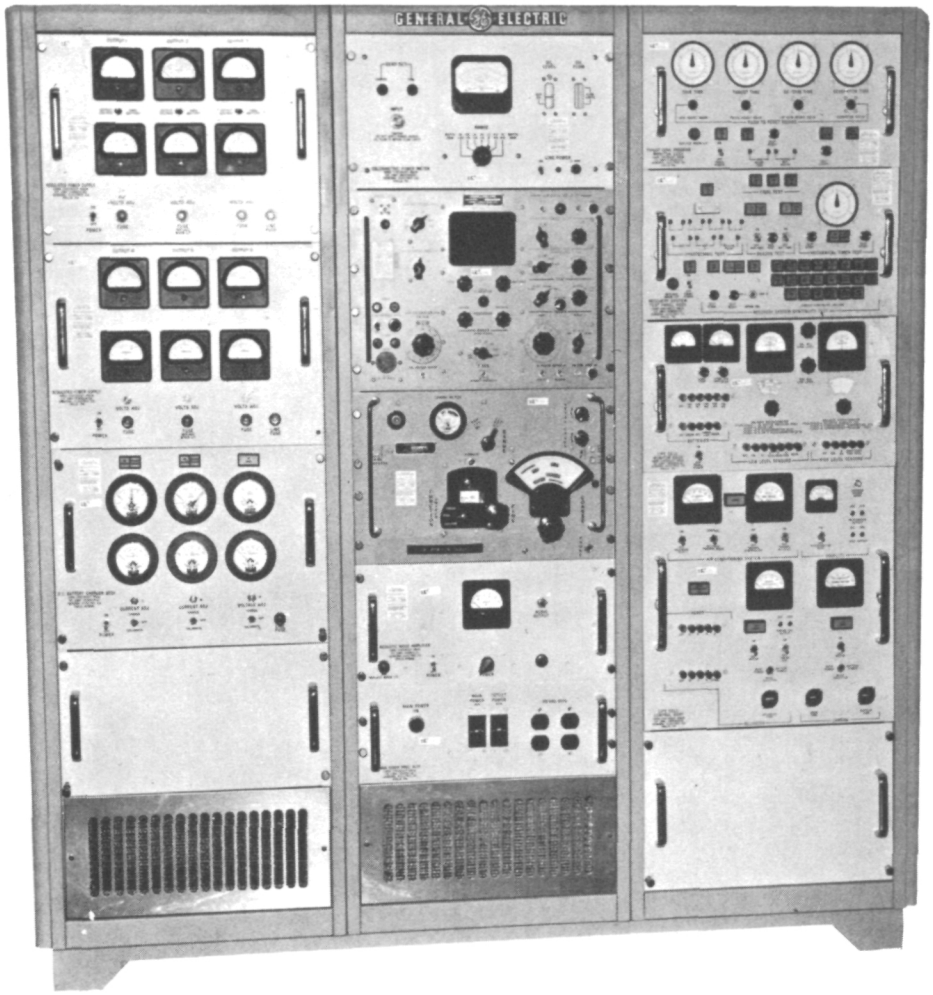


Figure B-57. Discoverer satellite vehicle test console

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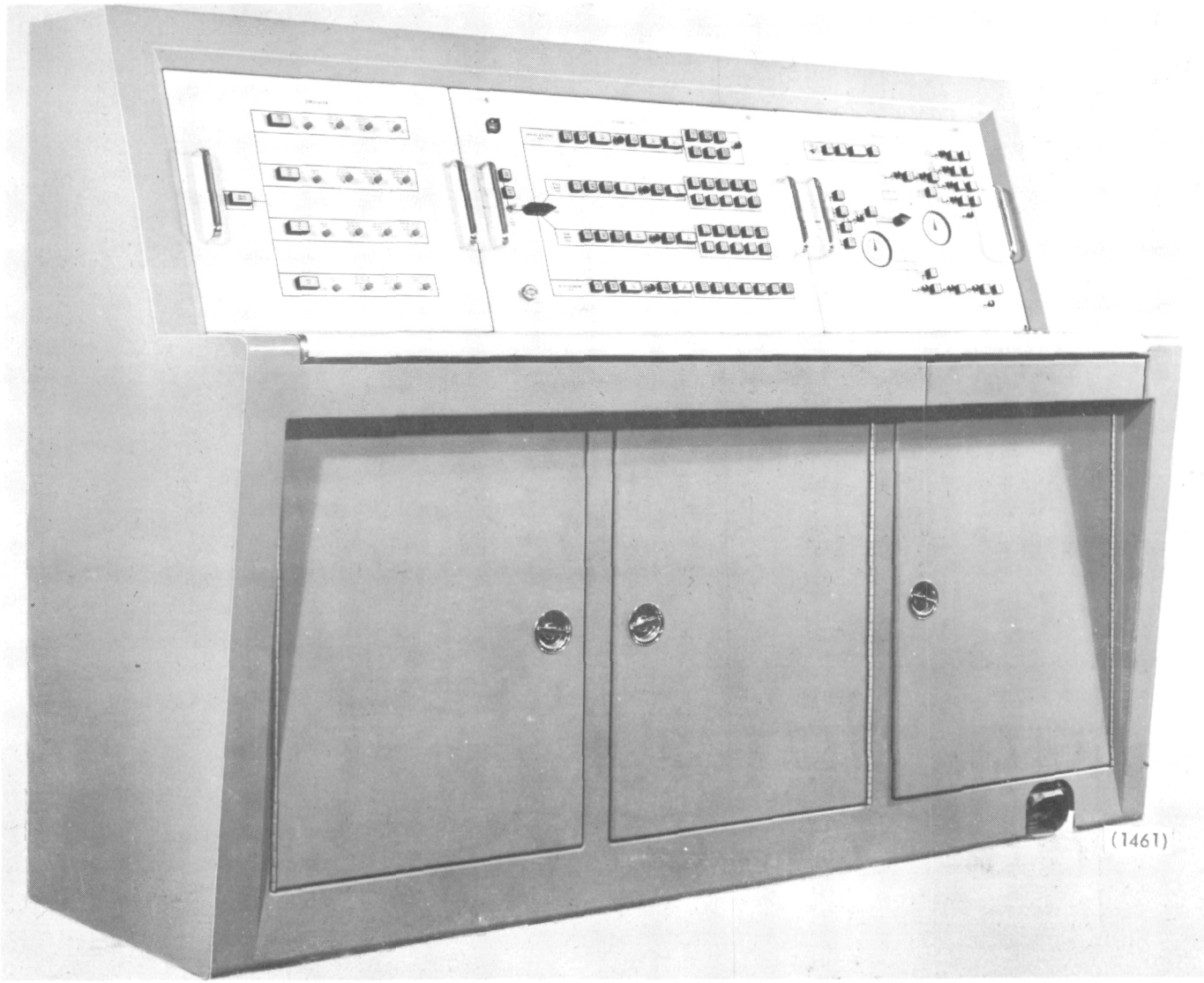

Figure B-58. THOR/ATLAS re-entry vehicle test console

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Figure B-59. MSVD test console (left) used for test and checkout of Mark 3 re-entry vehicle (right) R/V is mounted in special handling equipment developed by MSVD

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monitoring. Human factors were fully considered in the automation of critical test steps and logical presentation of test results.

3. Pre-launch monitor, Figure B-60, provides basic monitoring functions at the launch site.

4. Research and Development re-entry vehicle console, Figure B-61, which provides the versatility and adaptability required before operating characteristics of airborne equipment are fully established.

5. Handling and servicing equipment, Figures B-59, B-62, B-63, B-64, for THOR/ATLAS re-entry vehicles.

1.2.10 Aero-Space Technical Discipline Experience

1.2.10.1 AERODYNAMICS

Extensive aerodynamic programs including study analysis and experimentation in all phases of hypersonic ballistic flight are being conducted on a continuous basis as an integral phase of the Department's strategic systems work. From early 1956 to the present, MSVD's Space Sciences Laboratory has been experimentally studying and defining problems involving re-entry vehicle dynamics. Investigative programs have also been conducted in the low density wind tunnels at the University of California and Massachusetts Institute of Technology.

1.2.10.1.1 Hypersonic Aerodynamic Studies

MSVD has developed analytical techniques and has accumulated experimental test experience directly applicable to proposed program. These techniques and procedures can be used to evaluate real gas flow fields about blunt bodies, determine trajectories, loads, and dynamic behavior, and to determine aerodynamic characteristics in continuous and rarefied gas flow. Experimental tests (wind tunnel, shock tube, firing range, and free flight tests) have been performed in General Electric, government and suitable private facilities.

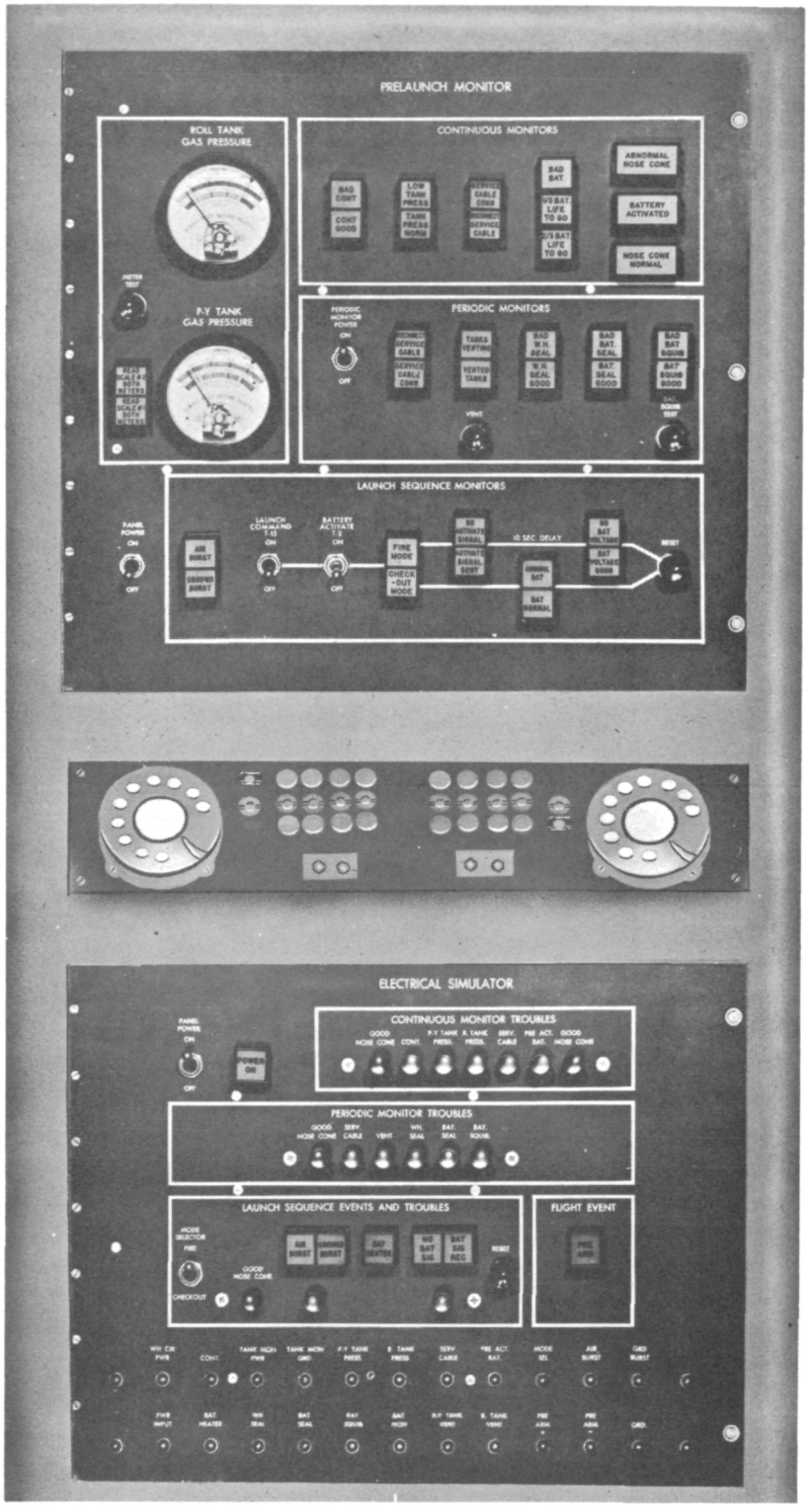

Figure B-60. Pre-launch monitor

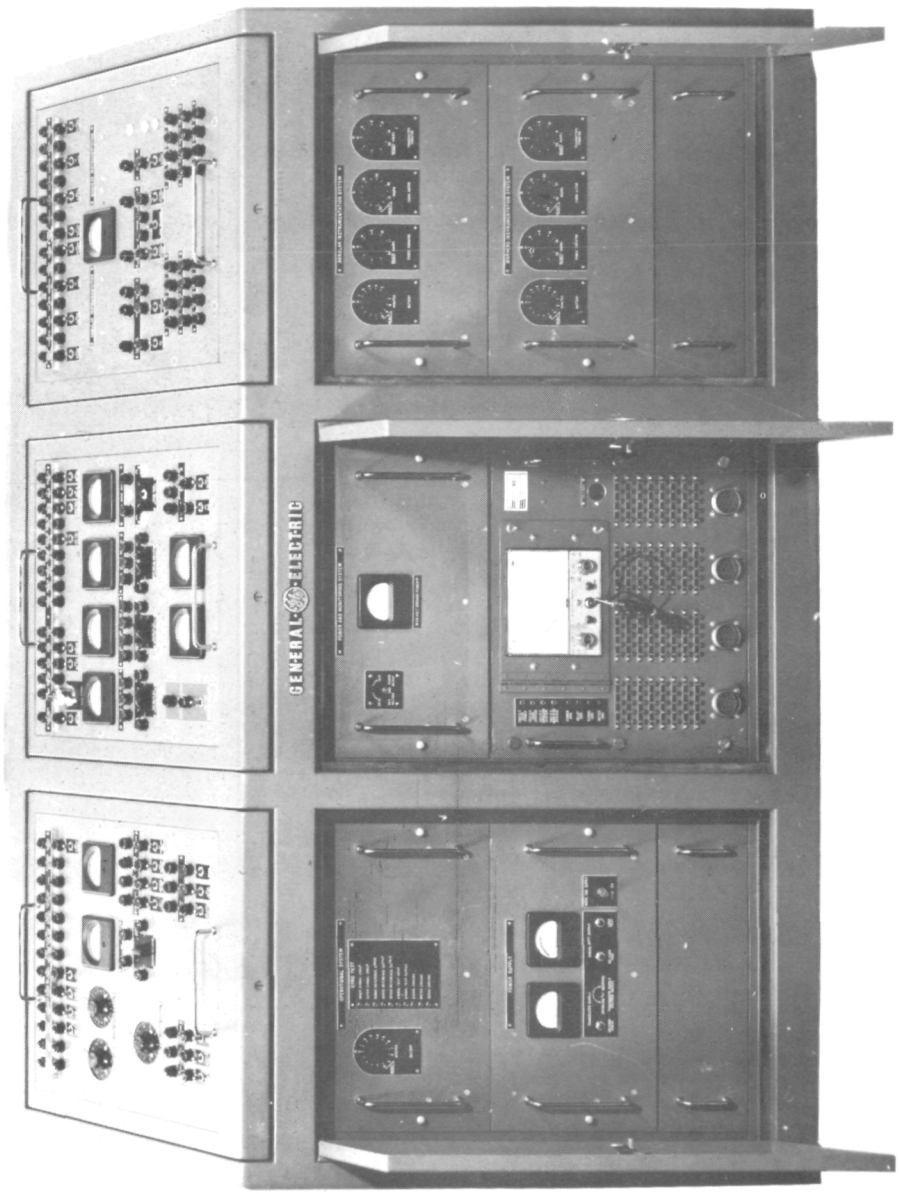

Figure B-61. R and D re-entry vehicle console

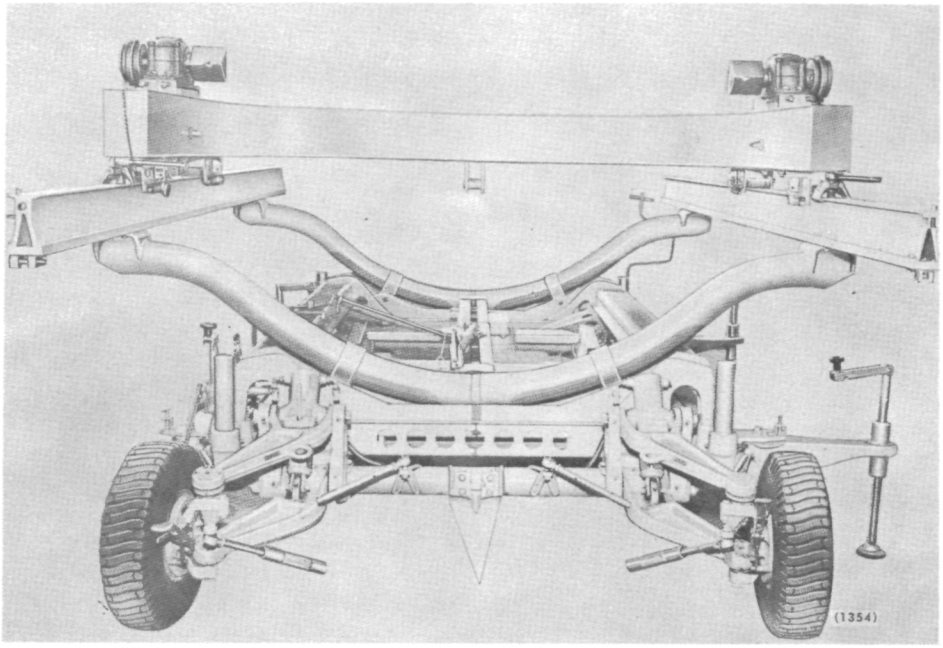

Figure B-62. Handling and servicing equipment

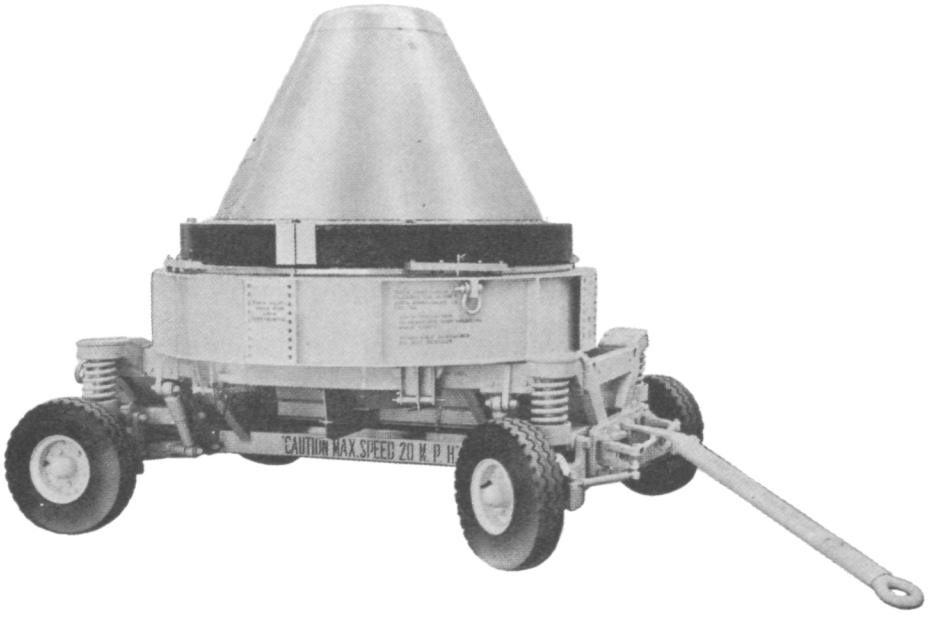

Figure B-63. Handling and servicing equipment

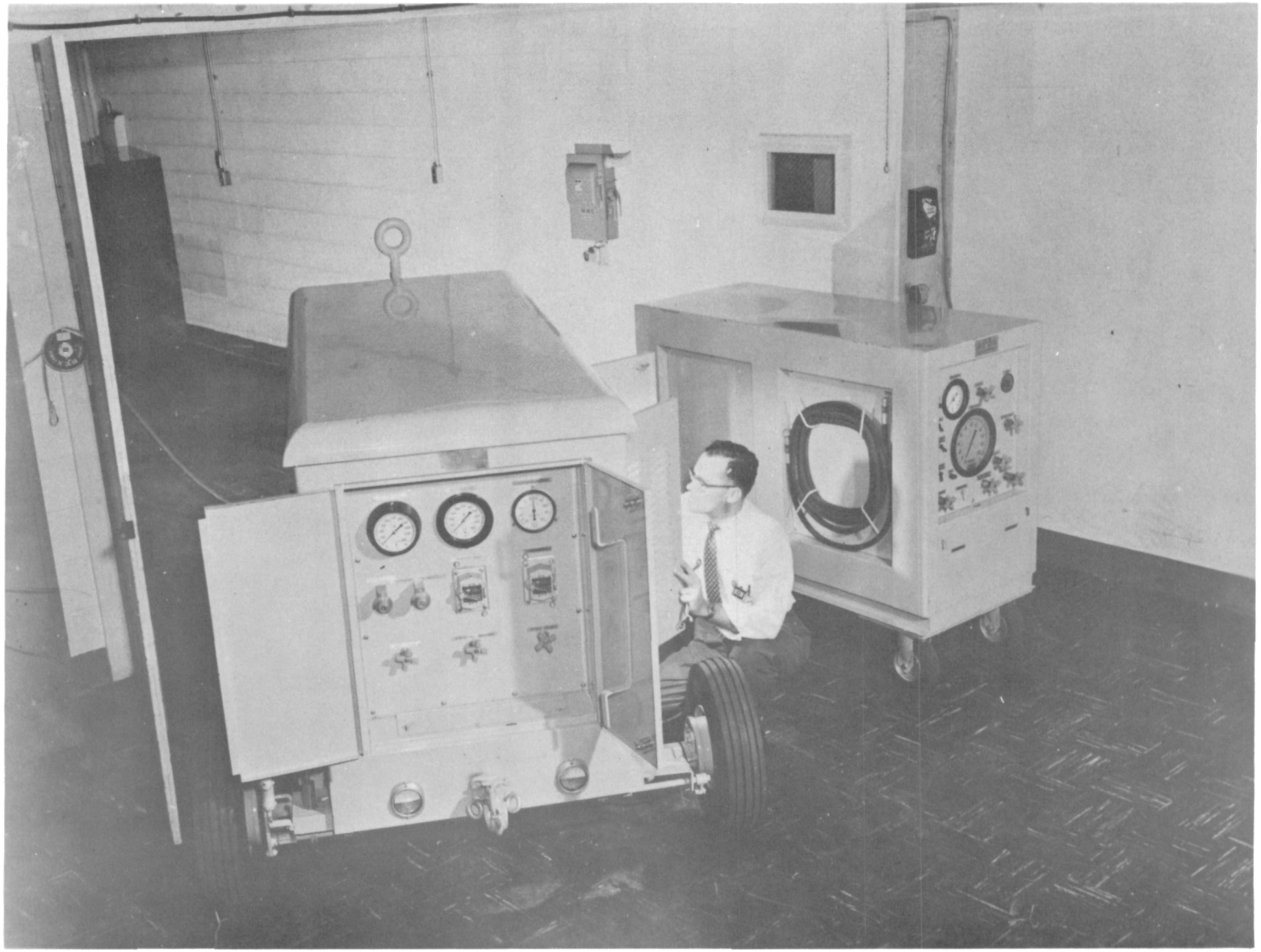

Figure B-64. Typical handling and service equipment

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1.2.10.1.2 Blunt Body Real Gas Flow Field

Real gas flow field data is being obtained on an IBM-7090 digital computer at MSVD, requiring as inputs only body geometry and trajectory data. An improved fast method for predicting pressure distributions has been evolved. Pressures at the edge of the boundary layer are determined for heat transfer calculations and aerodynamic load distributions. Also, ion-concentrations and distributions in the shock layer are evaluated for telemetry blackout possibilities (in R&D flights) and radar reflectivity characteristics. Flow fields on winged, aerodynamically maneuvering vehicles are being investigated.

1.2.10.1.3 Aerodynamic Characteristics

High supersonic force and moment coefficients (Cx, Cn, Cm, Cmg) of various blunt body shapes have been calculated for all angles of attack using the Newtonian theory to estimate all hypersonic coefficients and experimental data for lower Mach number performance variations. The effects of fin configuration, such as sweepback and platform area, on the vehicle aerodynamic performances were evaluated. Techniques for determination of aerodynamic characteristics of vehicles in rarefied gas flow have been determined by analytical investigation and experimental tests in low-density wind tunnels.

Other current programs include the study of aerodynamic characteristics by measuring the dynamic response of models of finned and glide-type vehicles in free flight in a hypersonic flow, studies of non-equilibrium flow in a hypersonic nozzle, magnetohydrodynamics, high temperature gas phenomena and electric arc plasma research.

In addition to work conducted at MSVD's Space Sciences Laboratory experimental work in hypersonic aerodynamics is conducted at the Research Laboratory in Schenectady. The facilities there include a hypersonic helium tunnel, shock tubes, and a hypersonic shock tunnel. In general, projects at the Research Laboratory have as their primary objective the development of understanding of physical phenomena. While this is a major factor in the experimental work of the Space

Sciences Laboratory as well, the latter laboratory is also charged with applied research in support of engineering design efforts.

1.2.10.2 THERMODYNAMICS

Since 1955, MSVD has been continuously working on the solution of re-entry heating problems. Theoretical and experimental studies have been directed toward obtaining highly reliable, light-weight heat protection systems capable of surviving re-entry thermal environments. Boundary layer analyses evolved during these studies will be valuable in the current study.

1.2.10.2.1 Aerothermodynamic Investigations

MSVD has conducted numerous theoretical studies to determine mass and heat transfer on a variety of re-entry vehicle configurations. Studies on ablation phenomena, including physicochemical considerations, have also been performed. Other work has included analysis of the aerodynamic heating of blunt, hypersonic glide vehicles, analysis of the heating of the leading edges of wings and fins, and evaluation of the attenuation of signals transmitted from bodies moving at hypersonic speeds. Various passive and active heat protection systems were examined to determine their applicability to a variety of heat flux-time environments typical of a wide range of ballistic and glide vehicle re-entries. Heat fluxes up to 8000 Btu/sq ft per second, and heating times up to 6000 seconds were considered. The systems studied included:

- Solid heat sink
- Ablation
- Point-mass addition
- Transpiration cooling
- Liquid metal cooling
- Film cooling
- Radiation cooling

1.2.10.2.2 Hypersonic Electromagnetic Effects

MSVD has conducted an investigation of electromagnetic effects associated with hypersonic vehicles under contract to Boeing Airplane Company. One of the objectives of this study was to describe the aerodynamic and thermodynamic characteristics

of the air in the flow field surrounding a typical hypersonic glide vehicle at various points along possible flight trajectories. An analysis was performed which determined the structure of the viscous boundary layer by iteration of the interacting inviscid and viscous layers.

1.2.10.2.3 Control Surface Effects

Recent investigations which have been conducted by personnel engaged in the study of re-entry phenomena has been a thorough examination of the surface pressure and heat transfer rate distributions on ballistic re-entry vehicle control surfaces. A fin-controlled re-entry configuration was selected for experimental parametric studies in the six-inch Shock Tunnel Facility; the Mach number range covered was 5.0 to 17.5. Zones of interest most closely examined were in the interaction regions at the fin-body junction and at the fin-bow shock wave intersection. Variations in geometry introduced concerned fin bluntness, deflection angle and sweepback as well as body angle of attack and bluntness. Results obtained were compared with existing analytical methods of prediction. The first portion of this program was reported in reference (1) at the end of this section describing Experimental Programs.

Further experimental studies of ablating materials were conducted, and conditions equivalent to a velocity of 18,000 feet per second at 200,000 feet altitude were simulated in an electric arc-heated supersonic wind tunnel. For satellite re-entry vehicles, the temperature rise at the back face of the heat shield is a significant item. Flight tests of models designed by MSVD at Mach numbers up to 15 and at temperatures up to 9000 F have been conducted in cooperation with NASA and the USAF. Several firing ranges have been used to obtain aerodynamic and stability data. The MSVD experimental programs in aerothermodynamics are categorized by facility in Figure B-65.

At present, MSVD has several programs scheduled for parametric studies of aerodynamic controls in support of the advanced design of hypersonic, aerodynamically-controlled, re-entry vehicles. These studies include aerodynamic effectiveness, thermodynamic performance, and heat protection of the controls.

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Program No.	Purpose	Facility*	Test Conditions	Data To Be Obtained	Remarks
1	Parametric aerodynamic effectiveness study of blunted wedge type fins. Shock layer pressure survey without fins.	AEDC B-2 tunnel.	$M = 8.0$ $Re_D \simeq 300 \times 10^6$ $\alpha = 2^\circ \rightarrow 14^\circ$ $\delta_p = 0 \rightarrow 15^\circ$ $\delta_1 = 0 \rightarrow 10^\circ$	C_{l_δ}, C_{m_δ}, C_{m_α} C_{L_δ}, C_N, C_{N_δ}, C_X, P_t, and P_x survey in shock layer.	Present consideration is for fins only. Flap configurations may be added to this program. Completed.
2	Define temperature gradients on fins and on body in region of fins. Define instrumentation requirements for detailed heat transfer and pressure studies.	AEDC B-2 tunnel.	$M = 8.0$ $Re_D \simeq 3.0 \times 10^6$ $T_t \simeq 900F$	Qualitative temperature gradients.	Temperature sensitive paint to obtain qualitative temperature gradient information. Completed.
3	Visualization of flow about fin and fin/body juncture.	NOL pressurized ballistic range.	$M = 6 \rightarrow 8$ $Re_D \simeq 3.0 \times 10^6$	Shadowgraph flow pictures.	Very limited program; will also attempt to obtain C_{l_p} and C_{l_δ} data.
4	Detailed pressure and heat transfer surveys on controls and in region of controls.	AEDC B-2 tunnel.	$M = 8.0$ $Re \simeq 3.0 \times 10^6$ $T_t = 900^\circ F$	Heat transfer and pressure measurements.	Transient heat transfer technique to be employed. Sensor locations to be optimized from program No. 2 above.
5	Obtain quantitative aerodynamic coefficient data and flow visualization information.	BRL transonic range. NOL pressurized range.	$M = 3.0 \rightarrow 8.0$	Drag, stability (static and dynamic), flow characteristics, C_{l_p}, C_{l_δ}.	
6	Control pitching effectiveness of high Mach number and low Reynolds number.	MSVD 6-inch shock tunnel.	$M = 12.6 \rightarrow 20$		

*FACILITIES: AEDC - Arnold Engineering Development Center
BRL - Ballistic Research Laboratory
NOL - Naval Ordnance Laboratory
MSVD - Missile and Space Vehicle Department, General Electric Company

Figure B-65. Current finned vehicle program

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Summarized in Figure B-66 is the current MSVD experimental program on finned vehicles. The results of these studies will aid in the evaluation of wing-body interference effects. The result of the MSVD experimental programs is the accumulation of an appreciable amount of information which is available and applicable to the present study effort.

1.2.10.2.4 Hypersonic Shock Tunnel Program

A hypersonic shock tunnel has been developed, under the direction of Dr. Henry Nagamatsu at the General Electric Research Laboratory, to investigate the aerodynamic characteristics of flow over bodies at conditions comparable to those encountered by ballistic missiles and satellites re-entering the atmosphere. Results have been obtained for a shock velocity of over 50,000 feet per second in the shock tube portion of the facility. Static pressure investigations were made in the nozzle for different stagnation conditions in order to determine the flow condition and the expansion process.

Results for representative blunt bodies at hypersonic Mach numbers and nozzle stagnation temperatures up to approximately 600 K were obtained. These include body pressure distributions, shock wave shapes, detachment distances, and photographs of the luminous gas region in the shock layer. (A more detailed description of the facility may be found in Memo Report C-58-264 of the GE Research Laboratory, November 11, 1958.) Dr. Nagamatsu has also conducted an investigation of slip effects at the leading edge of a flat plate at hypersonic speeds.

1.2.11 Launch Site Operation Experience

The Missile and Space Vehicle Department's Flight Test Engineering Operation (FLTEO) is located at Cape Canaveral, Florida and Vandenberg Air Force Base, California. Its personnel, numbering more than 100, have participated in a total of 94 missile and satellite launches since 1957.

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No. of Programs	Type of Facility	Data Obtained	Mach No. Range	Simulated Altitude	Stagnation Temperature
90	Wind tunnels.	Aerodynamic loads; performance; dynamic and static stability; heat transfer; flow studies; recovery systems.	0.6 to 19	Sea level to 250,000 feet	Ambient to 1800 degrees R.
50	Ballistic range.	Aerodynamic performance; dynamic and static stability; flow studies.	0.7 to 16	Sea level to 70,000 feet	Ambient.
15	High temperature.	Sensor development; development of ablation shield materials.	2.5 to 4	- - -	6000 degrees to 12,000 degrees R.
5	Model free-flight.	Heat transfer; load stability.	Up to 14	100,000 feet	9,000 degrees R.
6	Drop tests.	Recovery systems; stability; loads.	Subsonic and transonic.	50,000 feet	- - -

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Figure B-66. GE-MSVD programs in aerothermodynamics

This Operation, established in April, 1957, has been responsible for all tests, modifications, inspections, and readying-for-flight activity on all MSVD-manufactured re-entry and space vehicles. See Figures B-67 and B-68. From the time of its arrival at the test site, the vehicle is in the custody of FLTEO. Then, from the final minutes of countdown through launching and until the conclusion of the test, members of FLTEO are responsible for monitoring and recording the telemetry signals from the vehicle for later engineering analysis and data reduction.

Point Arguello and Vandenberg Air Force Base have been the sites for more than fifty successful missile, space probe, and satellite launchings supported by the Missile and Space Vehicle Department of the General Electric Company.

This record of accomplishment has been achieved by an experienced crew of more than sixty MSVD people permanently located at the Pacific Missile Range. This established organization, with a proven capability to perform efficiently and effectively, is familiar with operating procedures, test directives, and safety regulations and is well integrated into the day-to-day operation of the Range. The Missile and Space Vehicle Department, as the result of its work at the PMR on the ATLAS, THOR, DISCOVERER, and NERV programs, enjoys the reputation of a cooperative, competent contractor.

1.2.12 Data Processing and Computation Experience

Missile and Space Vehicle Department's Data Processing and Computation Operation is an integrated facility organized to serve the specialized needs of space vehicle research, development and test programs. It is staffed by scientists and engineers whose accumulated experience represents some 300 man-years of concentrated effort in this field, and is equipped with modern and extensive facilities.

The Data Processing and Computation Operation is currently performing engineering computation and data analysis for the United States Air Force, Navy, and Army

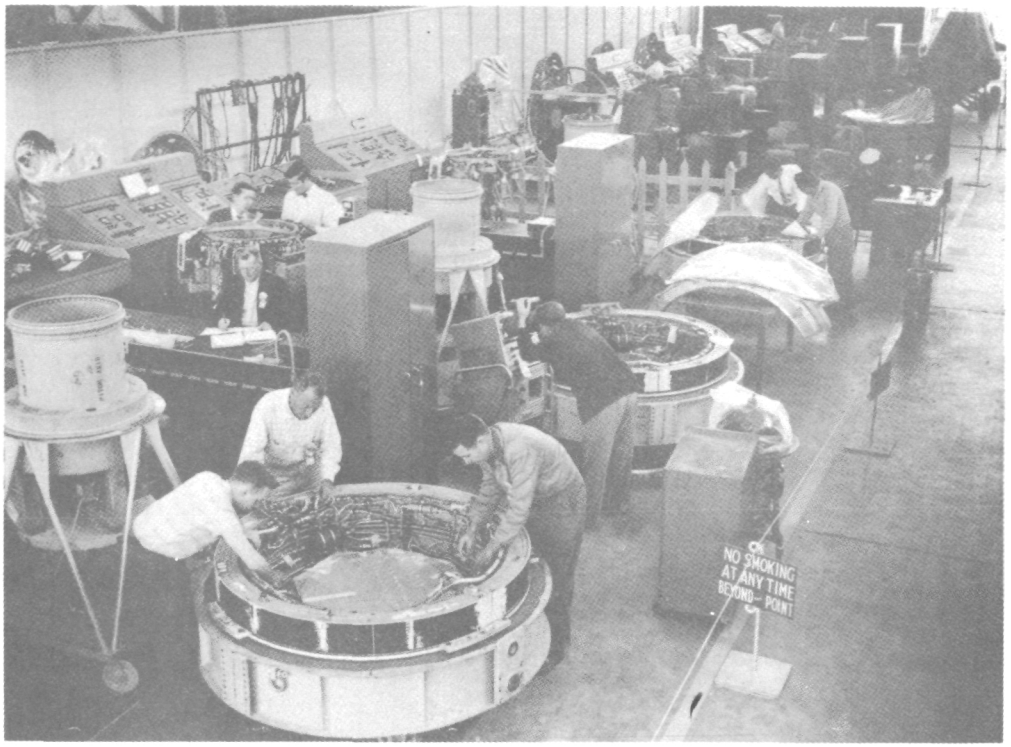

Figure B-67. Flight test operation

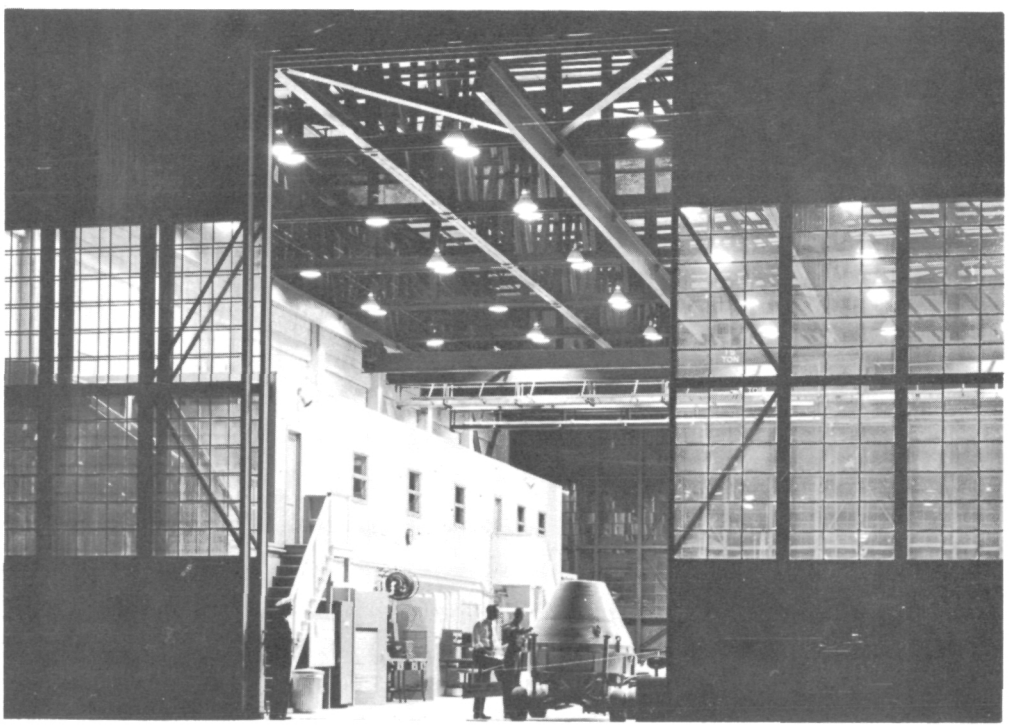

Figure B-68. MSVD flight-test hanger at AMR

programs. This organization specializes in the high speed reduction of field and flight-test data from the missile test center, White Sands Proving Grounds, Edwards Air Force Base and Vandenberg Air Force Base, in addition to processing data from factory, laboratory, and environmental tests. It provides a compiling, sorting, and filing service, as well as an integrated and highly mechanized technical data system for such subjects as history logs, failure reports and analyses, reliability tests, and logistics.

Future plans for the Data Processing and Computation Operation are directed toward a more automatic system for higher speed and greater efficiency and accuracy. Recent installation of an IBM 7090 has been a result of these plans. Improvements are now being made to provide for centralized control of existing equipment, and adaptation of that equipment to meet new requirements.

1.3 FACILITIES

In its sixteen years of experience in the field, the Missile and Space Vehicle Department and other General Electric departments and laboratories have acquired a comprehensive array of facilities and equipment. It represents one of the nation's greatest privately-owned facility complexes devoted to space vehicle development, manufacture and test.

The capability of the General Electric Company to identify and meet the facilities requirements of the APOLLO Spacecraft program is indicated in two ways: first, the quality and magnitude of facilities acquired by the Company to successfully perform past and present vehicle programs; second, by relating APOLLO requirements to types of facilities presently in place. It is the Company's intent to meet the APOLLO requirements with existing and new facilities of the type described in this section, as well as those of specialized subcontractors and suppliers.

The following are brief descriptions of the more unique and pertinent facilities now in place and under construction at the Missile and Space Vehicle Department.

1.3.1 Plant Facilities

Figure B-69 shows the master site plan and Figure B-69a shows a sketch of the Missile and Space Vehicle Department's new $32,000,000 Space Technology Center which was designed specifically to meet the requirements of manned space vehicle development such as the APOLLO Project. It is located on a 130 acre site at Valley Forge seventeen miles west of Philadelphia. Figure B-70 shows construction progress on the 800,000 square foot plant which will be completed late in 1961 in time for APOLLO. The center will contain MSVD general offices, engineering laboratories and shops, the Space Sciences Laboratory, the Space Simulators, manufacturing shops, and test facilities. An additional office building of 50,000 feet is occupied by MSVD at Valley Forge.

MSVD has additional plants in Philadelphia totaling more than 1,000,000 square feet of floor space devoted to the development of re-entry and space vehicles. An

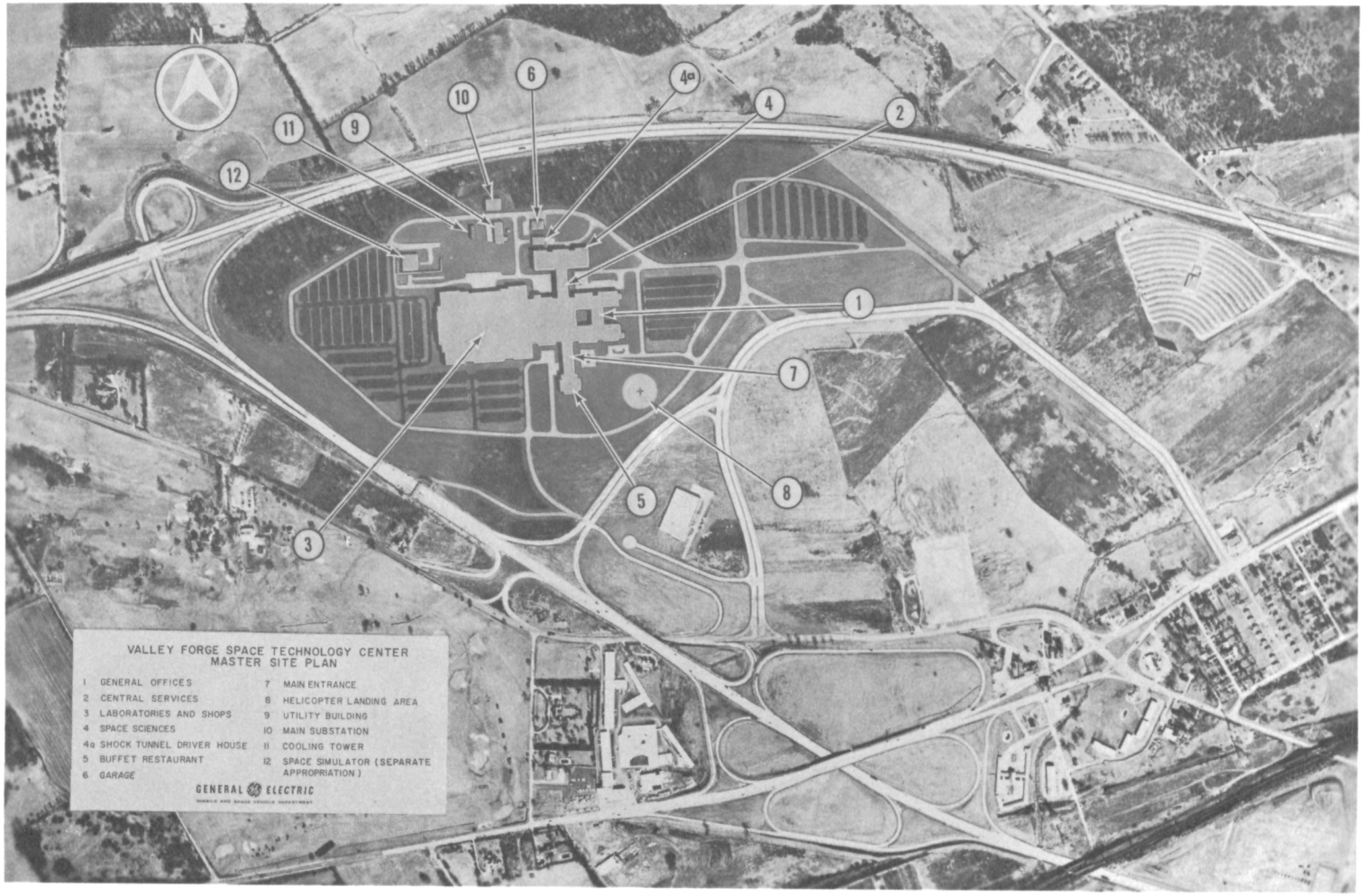

Figure B-69. MSVD Space Technology Center, Valley Forge, Pennsylvania - Plan

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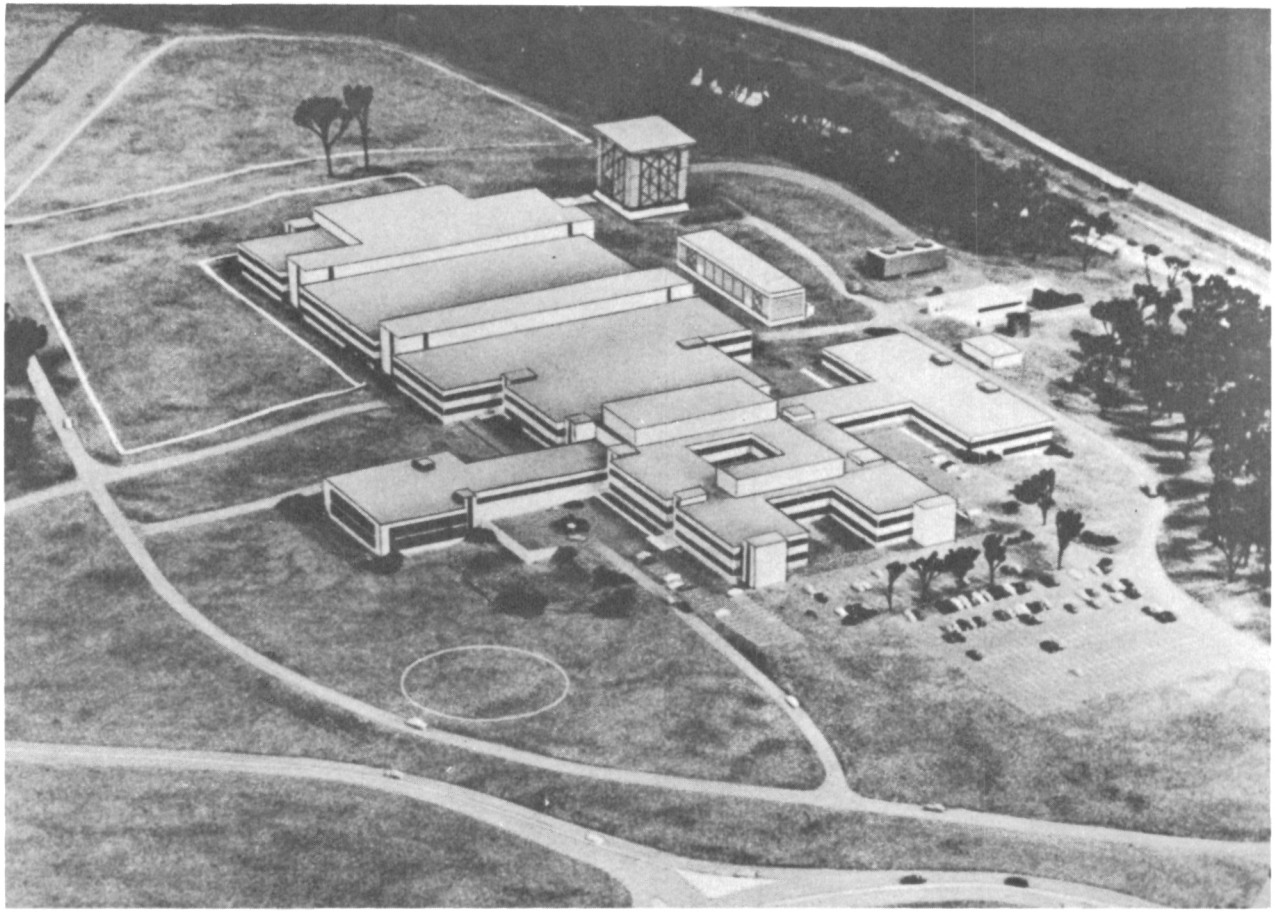

Figure B-69a. Space Technology Center, Valley Forge

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Figure B-70. Construction progress on MSVD Space Technology Center, Valley Forge

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additional manufacturing plant of 440,000 square feet is located in Burlington, Vermont. Therefore the nearly 8,000 MSVD people are supported by plant facilities of well over two million square feet.

1.3.2 Space Environment Simulators

Figure B-71 shows the $8,670,000 Space Environment Simulator with the APOLLO space vehicle shown for comparison. This simulator, which will be in operation in late 1961, will be employed for development, qualification and flight certification tests of subsystems, major modules and completely assembled space vehicles.

Figure B-72 shows the 32 foot diameter by 54 foot length chamber under construction and Figure B-73 shows the building housing the simulator at the Valley Forge Space Technology Center.

In operation, the simulator will closely approximate flight conditions in outer space. Thus, full-size vehicles and components may be tested under controlled conditions in an accessible location. Ten ton vehicles up to 20 feet in diameter and 35 feet long may be tested for as long as 2,000 hours in a pseudo-space environment which includes:

- Low temperature - down to 77 degrees Kelvin.
- Low pressure - 10^{-9} mm Hg.
- Solar radiation - 130 watts/ sq ft in the spectral range from 1800 to 3000 angstroms
- Black body surroundings - chamber wall emissivity of less than 1 percent
- Earth albedo and emitted infra-red radiation.

Four types of pumps - mechanical roughing pumps, diffusion pumps, nitrogen and helium cryogenic pumps - with a combined capacity of 70 million liters per second will evacuate the chamber within four hours. The cryogenic pumps produce wall temperatures as low as 20 degrees Kelvin, causing condensible gases to collect

APOLLO IN SPACE SIMULATOR

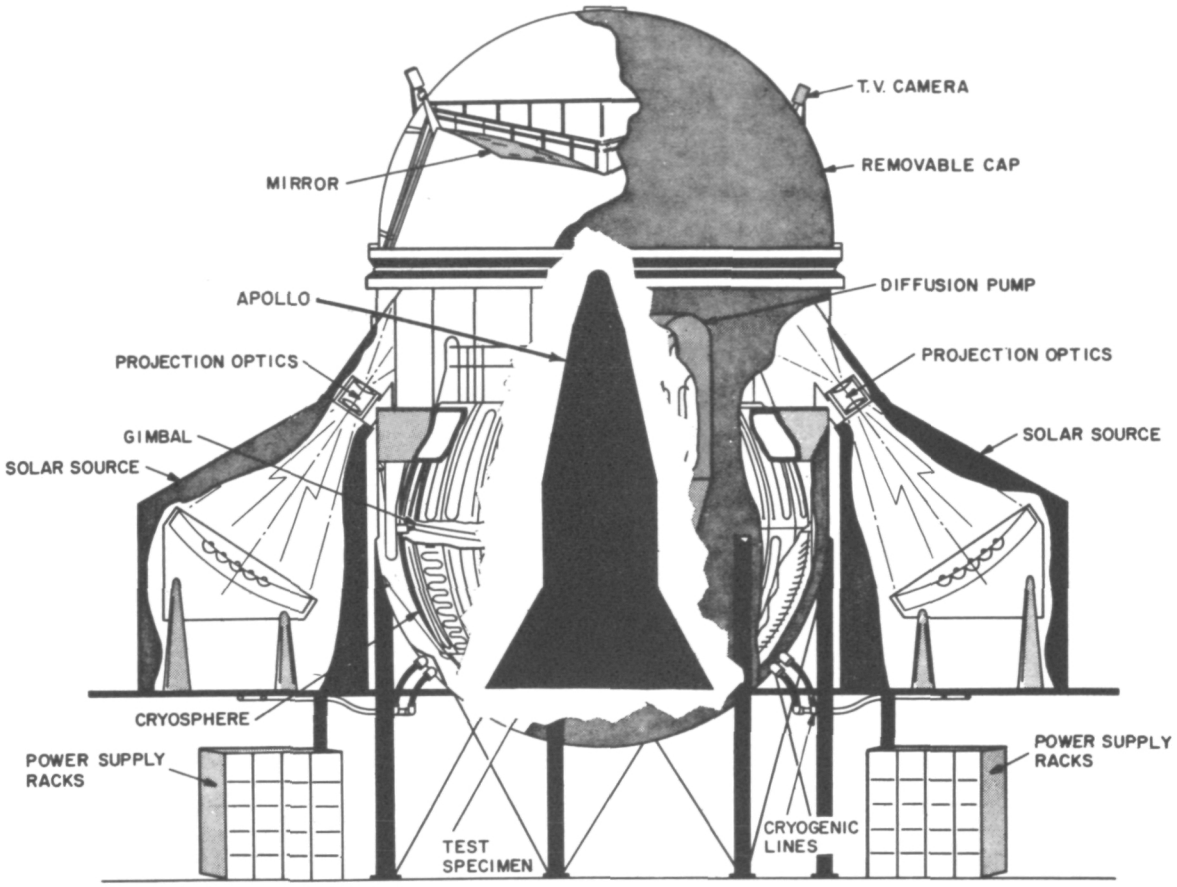

Figure B-71. Space environment simulator

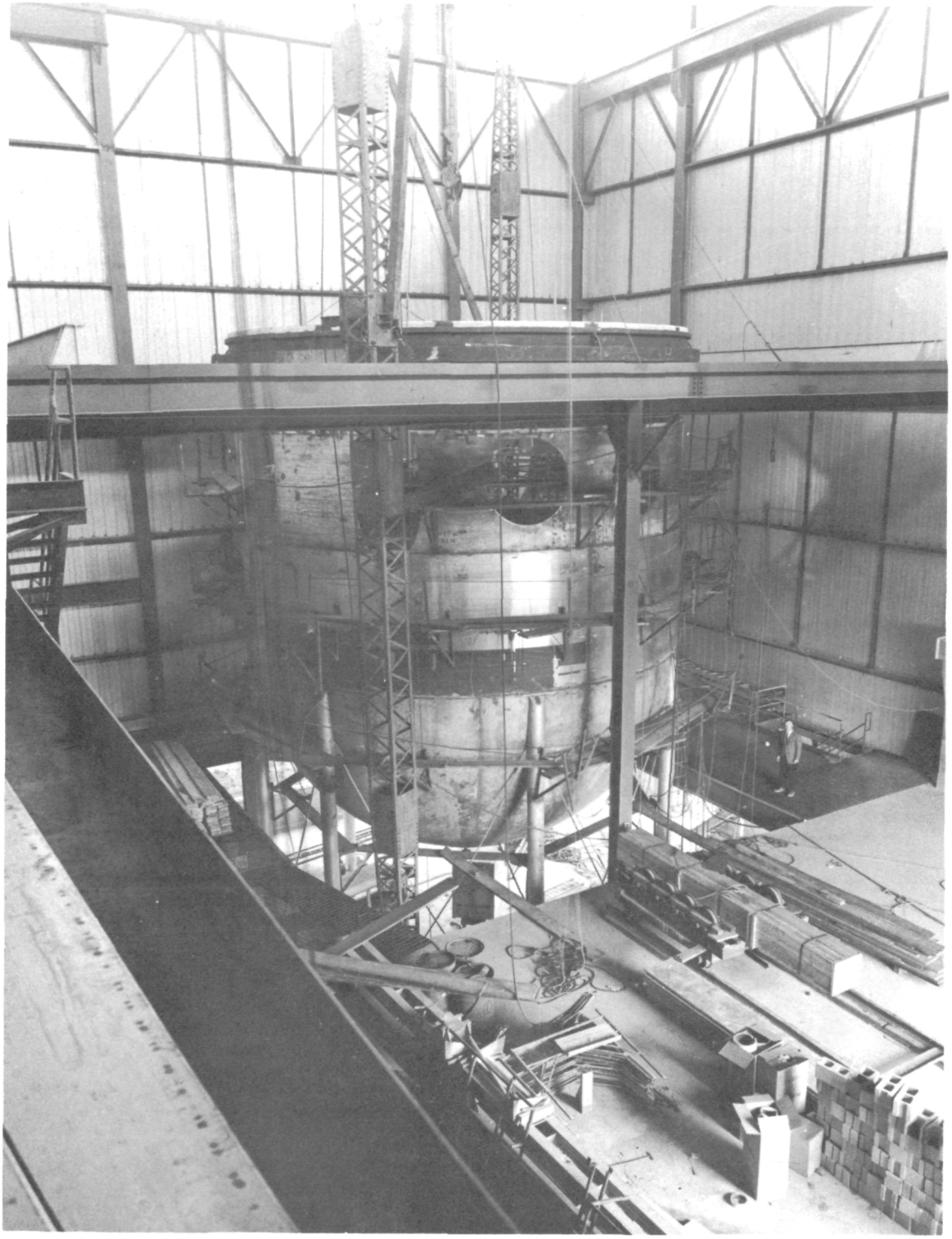

Figure B-72. Space simulator chamber under construction

Figure B-73. Space simulator building

on the black aluminum panels and thus reduce pressure to the low level. (It is estimated that 250,000 gallons of liquid nitrogen and three million standard cubic feet of helium gas will be pumped through the walls of the simulator, daily.)

A special 5 kw xenon arc lamp is being developed by the General Electric Lamp Department, to simulate solar radiation. Four banks of these lamps, each containing 37 lamps, will direct energy through an optical system to a 22-foot mirror which will direct the collimated beam onto the test vehicle. The accuracy with which the sun is to be simulated will be beyond any existing (or known planned) private facility.

The mechanics of actual flight can be simulated in the chamber through the application of dynamic, three-degree-of-freedom rotational forces at one-G levels, and vibration in the frequency range from 20 to 2000 cps, at half-inch amplitude.

The following are other simulators MSVD has or will have available by early 1962. These are used for component and subsystem development and qualification testing for programs currently active at MSVD.

1.3.2.1 SPHERICAL SPACE SIMULATORS

Three 39 foot diameter spherical space simulators costing $4,000,000 are being constructed for other MSVD programs. They will be completed by March 1962. They have the following capacity:

- Low Temperature - down to 100 degree Kelvin
- Low Pressure - 10^{-6} mm Hg.
- Solar Radiation - 390 watts/sq ft

1.3.2.2 COMPONENT CHAMBERS

Four 5 foot diameter by 5 foot long chambers costing $630,000 will be available by September 1961. They have the following capacity:

- Low Temperature - down to 100 degree Kelvin
- Low Pressure - 10^{-6} mm Hg.
- Solar Radiation - 390 watts/sq ft

1.3.2.3 SUBSYSTEM CHAMBER

One 10 foot diameter by 12 foot long chamber costing $230,000 will be available by June 1961. It has the following capacity:

- Low Temperature - down to 100 degree Kelvin
- Low Pressure - 10^{-8} mm Hg.
- Has a vibration feed through a port.

1.3.2.4 PROTOTYPE SPACE ENVIRONMENTAL SIMULATOR

Figure B-74 shows the 3 foot diameter by 4 foot long prototype of the large Space Environmental Simulator which was used as a development tool for designing the large simulator. It can be used for component and subsystem tests. It cost $300,000 and has the following capacity:

- Low Temperature - down to 100 degree Kelvin
- Low Pressure - 10^{-7} mm Hg.
- Solar Radiation - 130 watts/sq ft

1.3.2.5 VACUUM BELL JARS

Figure B-75 shows two of the twenty-three 18 to 24 inch diameter by 18 to 24 long vacuum bell jars costing a total of $350,000. They go down to 10^{-6} mm Hg.

1.3.3 Data Processing and Computation Center

A $5,500,000 integrated data processing and computation system of men and machines has been set up within the Missile and Space Vehicle Department to meet the demands of complex missile and space system development programs ranging from initial design to final testing evaluation. A diagram of this system is shown

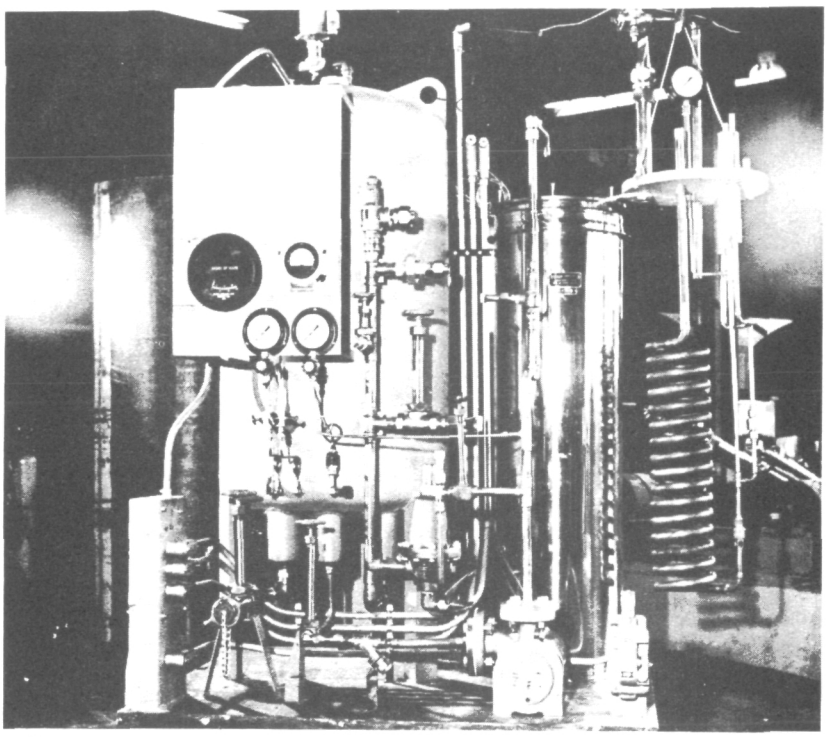

Figure B-74. Prototype space environmental simulator

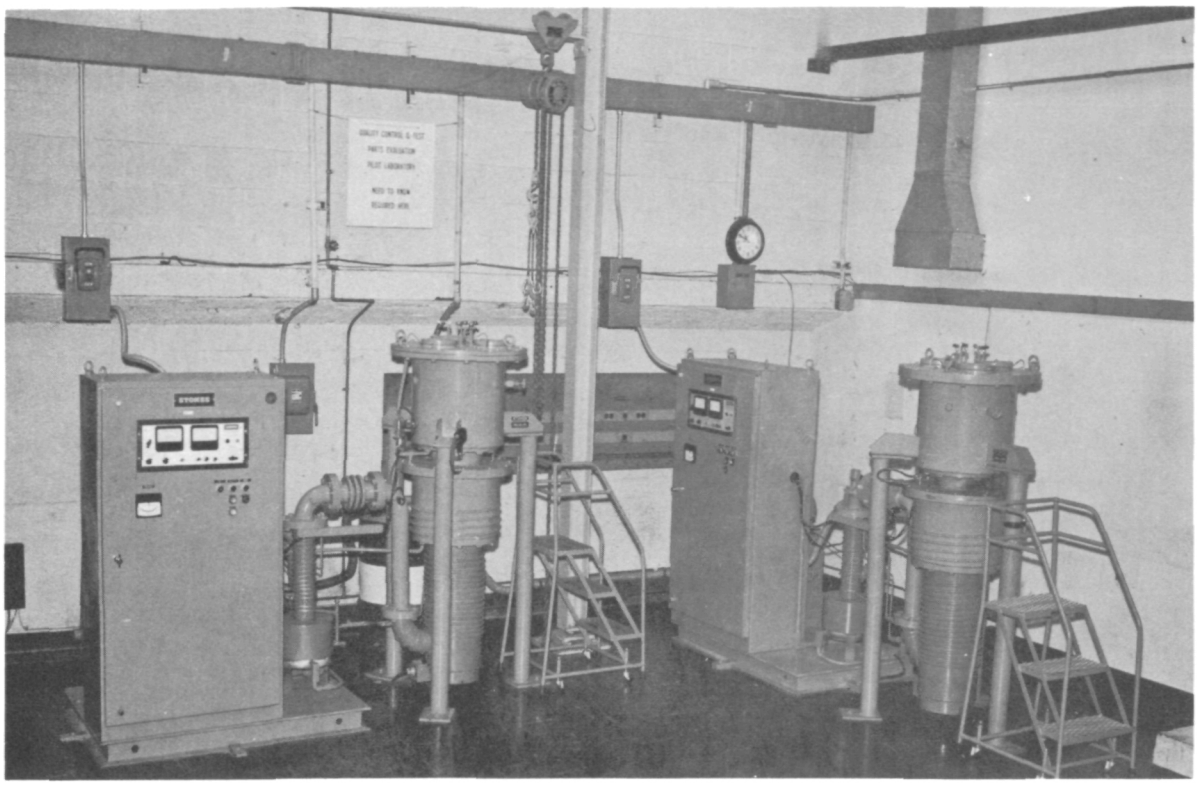

Figure B-75. Vacuum bell jars

in Figure B-76. The heart of the data processing facility is an IBM 7090 Electronic Data Processing Machine. This new IBM 7090 has recently been added to the IBM 704 system. The IBM 7090 (See Figure B-77) is a large-scale, high speed, single-address, general-purpose calculator controlled by internally stored programs. It is capable of performing 200,000 mathematical processes per second, which is approximately three to five times the speed of the IBM 704.

Point-mass trajectories have been programmed on the computers for determining the dispersion introduced by variations in atmospheric density, winds, and the physical characteristics of the vehicle. A six-degree-of-freedom study has been made by obtaining numerical solutions of the complete three-dimension equations of motion. This program has been used extensively to predict motion characteristics during flight. An N-stage powered flight trajectory computer program has been developed for determination of powered flight conditions applying to the

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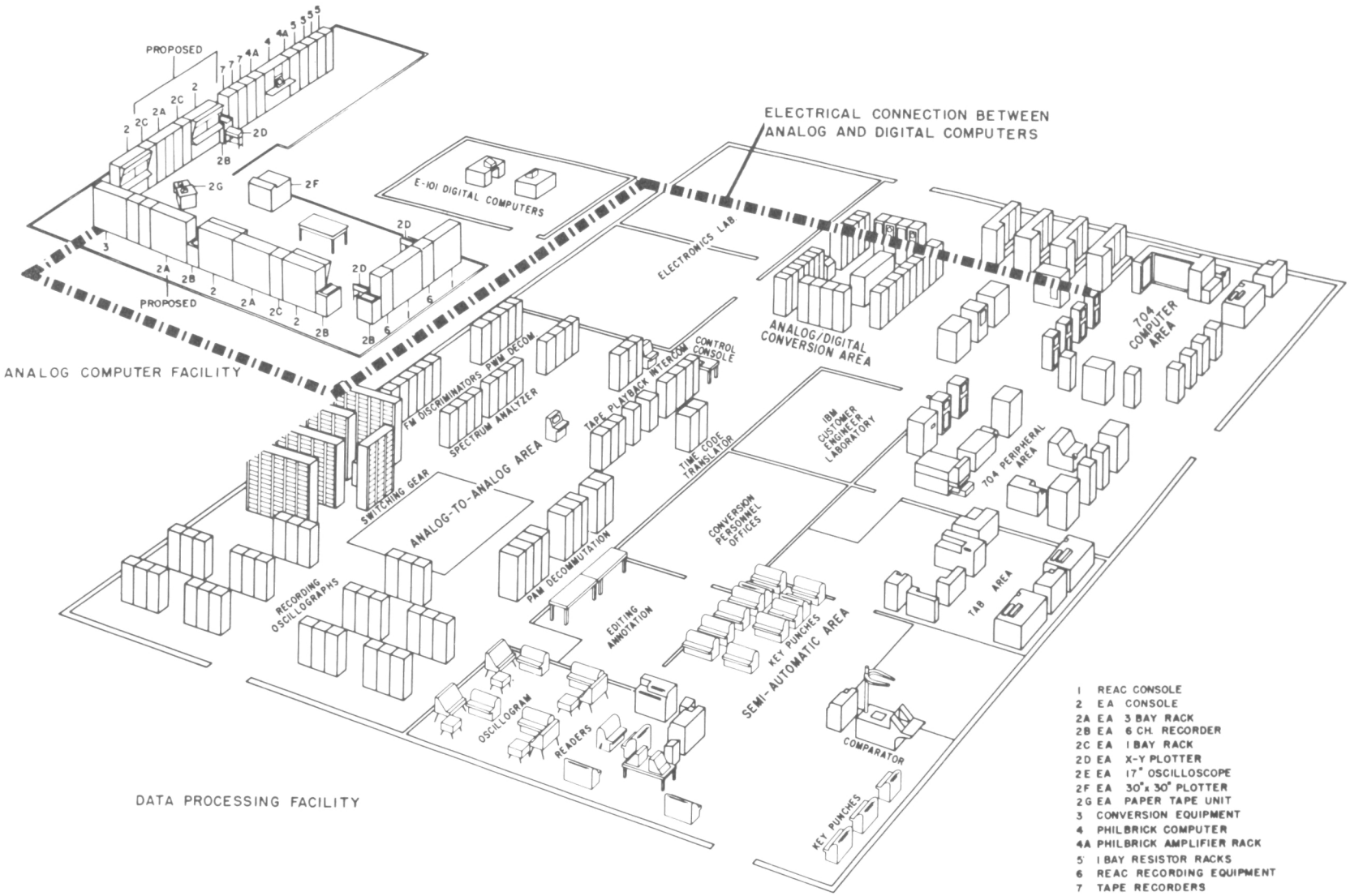

Figure B-76. Integrated data processing and computer center

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Figure B-77. IBM 7090 installation (top)
and IBM 7090 console (bottom)

maximum performance trajectories. These programs exemplify the trajectory calculation capability of the Department's data processing facility.

The speed and utility of the MSVD data processing facility have been amply demonstrated on present flight test evaluation programs. Analog plots have been produced within a few hours from magnetic tapes involving over 100 separate telemetry channels. Preliminary reports on the major aspects of the performance of IRBM and ICBM re-entry vehicles have been prepared within three days after flight. Final engineering analyses are usually accomplished within ten days following a test flight. The versatility of the data processing facility has enabled MSVD to complete flight test summary reports within 30 days following major tests.

Analog computer equipment shown in Figure B-78 is available to design engineers for control-system analysis and simulation, as well as for the solution of simultaneous differential equations and for the simulation of physical conditions involved in problems of heat and mass transfer, stability, and boundary layer conditions.

Analytical investigations can be made of the various components comprising the control, measurement, and transmission functions. Analog computers operated on a one-to-one scale can also be used with actual components to simulate the functions of certain portions of the payload carrier.

MSVD has made extensive use of computer simulation in the design of various control systems. For example:

(1) A six-degree-of-freedom analog simulation was used to test variations of cross products of inertia, gas energy supply, torque-to-inertia ratio, and other variables.

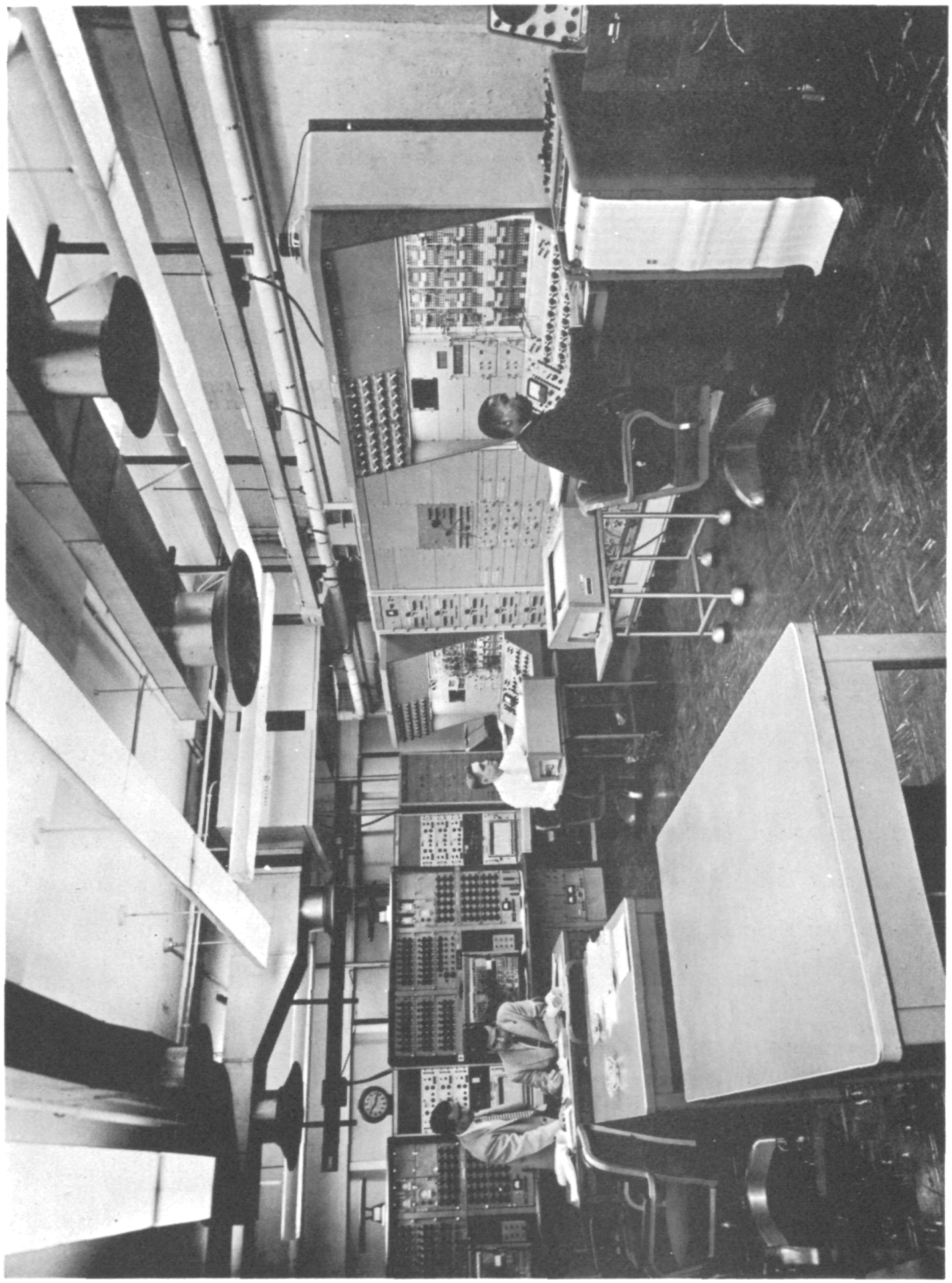

Figure B-78. Analog computer facility

(2) A three-degree-of-freedom study was conducted with a completely simulated thrust system, a three-axis flight table, connected with and operated by an analog computer programmed to compute inertial angles in real time.

(3) A one-degree-of-freedom simulation was done using a complete mechanical simulator with actual components.

MSVD has a hybrid computer link (Hycol) which joins the analog computer facility and the IBM 704 and 7090 digital computers. This facility offers the significant advantage of combining high accuracy of the digital with high speed of the analog computer.

The system furnished a new problem solving capability. Hycol has many applications, some of which are: matrix solving, mathematical simulation of systems, and physical simulation of systems, such as missile attack and defense systems, rendezvous, etc.

One unique feature of Hycol is its ability to vary the data transfer rate automatically as dictated by the condition of the problem.

1.3.4 Space Sciences Laboratory

A major portion of MSVD's advanced research and experimentation is conducted by the Department's Space Sciences Laboratory. Figure B-78a show the resources of the laboratory. This outstanding facility is noted for its many contributions to missile and space technology; particularly in the evolution of practical designs, materials, and processes capable of operation and survival under the unique stresses and destructive forces associated with hypersonic velocities as high as Mach 10 and above. The areas of investigation covered by the Space Sciences Laboratory include such diverse and related subjects as ablation, aerodynamics, arming and fuzing, ballistics, biotechnology, chemistry, communications, ecology, guidance, impact, ionization, materials, nuclear effects, plasma dynamics, shock,

MANPOWER

125 PROFESSIONAL

53 PHDs

11 PHYSICISTS

14 PHYSICAL CHEMISTS

28 MATHEMATICIANS, CHEMISTS, OTHERS

374 TOTAL EMPLOYEES

MAJOR FACILITIES

AERODYNAMICS & PLASMA PHYSICS FACILITIES
- 6" SHOCK TUNNEL
- 6" MW CARBON ARC
- 5" CLEAN ARC TUNNEL
- 2" SHOCK TUBES
- PLASMA PROPULSION

PLASTICS DEVELOPMENT LABORATORY

HIGH EXPLOSIVE TEST FACILITY

PHYSICAL CHEMISTRY LABORATORY

MATERIALS RESEARCH LABORATORY

APPLIED MECHANICS LABORATORY

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Figure B-78a. MSVD space sciences laboratory resources

thermochemistry, thermodynamics, and others. Of special importance to future developments in missile and space science are the studies and analyses of the physics and dynamics of partially-ionized gases and the thermochemical and shock characteristics of materials and structures, particularly as they apply to advanced missile and space vehicles.

The knowledge gained through such research is carefully applied to the design of missiles, space vehicles, and associated equipments which will be subjected to the extreme conditions of structural stress temperature, speed, and pressure encountered in space flight. Thus, scientific proof of feasibility is established before new design concepts are accepted for full-scale development.

Several unique operational and experimental testing facilities are available for use on investigative programs of hypersonic aerodynamics, structures, and related high temperature phenomena. These facilities are described below.

1.3.4.1 SIX-INCH SHOCK TUNNEL

The shock tunnel is essentially a blow-down wind tunnel which employs a shock tube to provide a working gas of high stagnation enthalpy and pressure. Wide ranges of flow Mach number, Reynolds number and stagnation enthalpy are obtainable in this tunnel facility.

Figure B-79 illustrates the MSVD shock tunnel facility. The driver tube is 22 feet long with an eight inch inside diameter and a design pressure of 10,000 psi. It can be operated either by the combustion of a light gas mixture or by charging to pressure with a single inert gas depending upon the test conditions desired. The driven tube, composed of several interchangeable sections, is 112 feet long, has a six inch inside diameter and a design pressure of 5,000 psi. At the downstream end of the driven tube, a 30 degree included angle conical nozzle leads to a test section of 30 inches in diameter. Test models may also be located at any smaller diameter section of the nozzle depending upon the flow conditions desired.

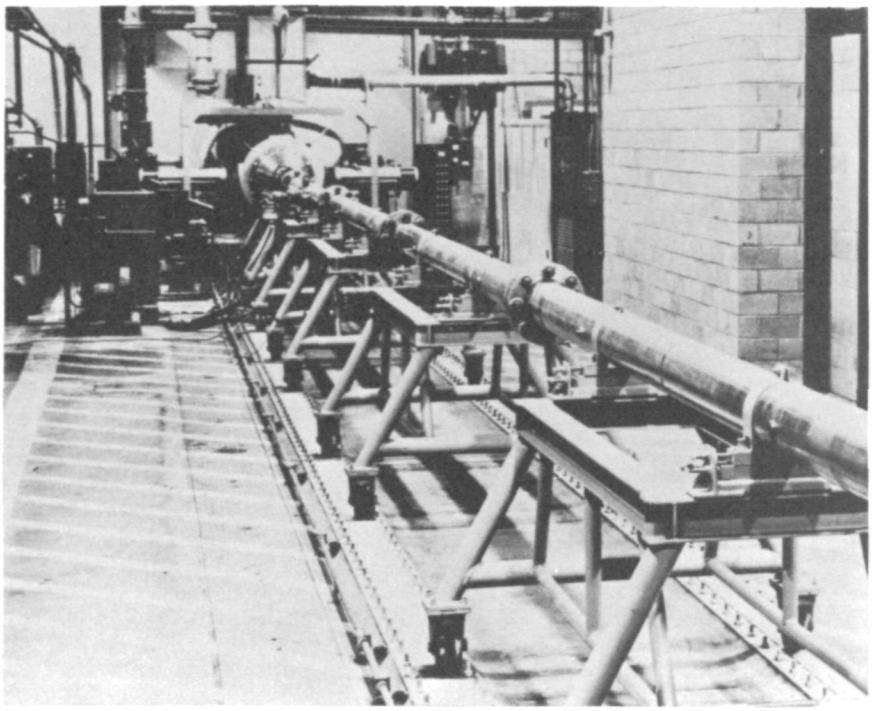

Figure B-79. Six-inch shock tunnel in aerosciences laboratory

1.3.4.2 TWO-INCH SHOCK TUBES AND TUNNEL

Several smaller shock tube facilities are operable, both in support of experiments programmed in the 6 inch facility and for specialized gas dynamics studies to which these instruments can be readily tailored. These tubes perform in much the same manner and in the same pressure ranges as the larger tube, being subject to the economies of smaller scale operation and handling but limited in scope of aerodynamic test versatility.

The tubes vary in length from 10 to 37 feet excluding tunnel attachments. Inside dimensions of the driven sections are nominally two inches round or square. The tunnel has a conical nozzle with a test section of 10 inches diameter; two dimensional nozzles are also available. A low pressure tube can be evacuated down to the submicron range and is especially suited to the dynamic calibration of pressure transducers down to 0.001 psia.

Instrumentation available is similar to that listed with the 6 inch Tunnel but on a quantitatively reduced scale. In addition, high speed drum camera recorded, time resolved interferograms and spectrograms of dynamic gas properties can be made, simultaneously if required.

1.3.4.3 SIX-INCH SHOCK TUBE/GAS GUN

This facility employs a large bore shock tube to accelerate a mass to collide against a stationary target, thereby providing a controlled source of high kinetic energy for simulation tests on components and devices which are designed for impact actuation, for the study of structures subjected to high rates of loading and for the investigation into the effects of impact phenomena as such.

The shock tube (or gun) has a bore diameter of six inches and a projectile travel length of 25-1/2 feet. The tube muzzle end extends through a four foot thick wall into an impact shelter in which are contained the target, target holder and such instrumentation as may be required. A sabot stripping muzzle attachment is available for use with sub-caliber projectiles. The pressure chamber has a nominal capacity of two cubic feet and is currently restricted to an inert gas pressure of 1000 psi, although a capability towards much higher pressures and combustion operation exists.

Instrumentation to record the velocity of the projectile as it emerges from the muzzle, high speed photography (both motion and still), event triggering devices and electronic recording instruments are available for use with this facility.

1.3.4.4 SHROUD NOZZLE AIR ARC

In this facility an electric arc unit powered by a 200-KW DC motor-generator bank is used to heat air (or another gas) prior to its passage through a nozzle constricted by the test specimen around which this high enthalpy air at 5000K is made to flow. With the mass flow of the incoming air metered and regulated the stagnation pressure is controlled by maintaining the proper annular clearance between the test specimen

and the nozzle wall, even as the specimen surface recedes. The specimen is positioned into the nozzle after the hot flow has stabilized and is withdrawn after a predesignated test time has elapsed at which time the unit is shut down. Test times ranging up to 30 seconds are normally established depending upon the material and heat level specified.

The shroud arc is a useful tool for studying the stagnation region ablation of materials of interest for re-entry vehicle applications. Test conditions simulate stagnation point properties corresponding to free flight velocities of about 18,000 ft/sec at altitudes of 100,000 feet.

Types of test specimen data which are obtained:

1. Ablation length recession vs. time
2. Ablation mass loss vs. time
3. Sub-surface temperature rise vs. time
4. Surface pressure gradients and calorimeter heat transfer rates in the stagnation region.
5. Surface, sub-surface, and internal damage penetration and characteristics.

1.3.4.5 ARC HEATED WIND TUNNEL

Another laboratory facility, shown in Figure B-80, capable of furnishing experimental data of interest is a supersonic wind tunnel which utilizes a supply of continuously heated air provided by an electric air arc unit similar to that in the shroud facility. Here the high enthalpy air is expanded in a Mach 4.8 nozzle into a continuously evacuated test section to simulate model stagnation conditions at high altitudes, above 200,000 feet. The relatively lower heating rates available coupled with water cooling of the temperature sensitive components permit tests

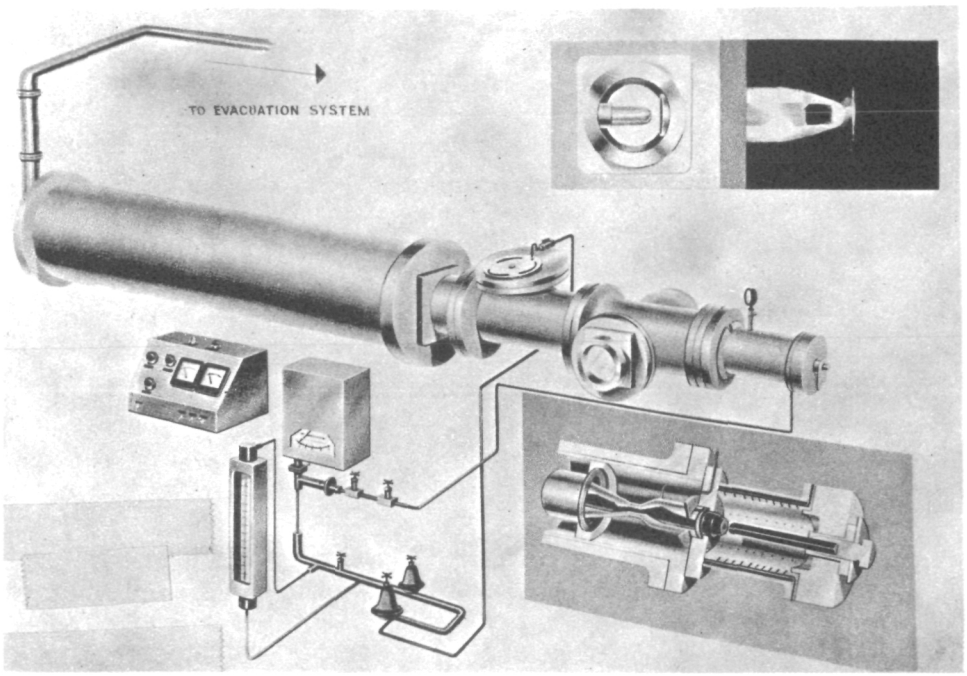

Figure B-80. Electric arc heated supersonic wind tunnel

of over 15 minutes continuous duration to be conducted, thus providing a test medium for studies involving non-steady state effects. Models up to 1-1/2 inches in diameter with various frontal configurations may be tested in this facility when fitted with a conical nozzle; specimens to 4 inches across by 1/2-inch thick can be accepted for test with a rectangular nozzle installed.

Model test data achievable in the arc tunnel includes those kinds listed for the shroud facility and the additional capability of obtaining photographic and visual observations of the model and flow during testing.

1.3.4.6 2500 KW AIR ARC

The study of many aerothermodynamic problems encountered in the supersonic aerodynamic field requires the availability of long-time, large-scale, high-temperature aerodynamic test facilities. The 2500-kw air arc facility developed at MSVD satisfies many of the requirements of experimental studies in this problem area. This device provides high temperature gases which have been passed through a three-phase a-c arc and an appropriately sized plenum chamber. Thus this unit, like the much smaller d-c units previously mentioned, is primarily a gas heater from which many experimental configurations can be operated.

A photograph of the large air arc is shown in Figure B-81. The 2500 kw rating refers to the nominal power added to the gas; that is, approximately 7000 kw of power must be delivered to the unit to provide this gas power level. Actual operations in certain test programs have involved power levels of two to three times these values. Nominal plenum pressure and stagnation enthalpy values for this facility are 10 atmospheres and 6700 Btu/lb respectively.

Two types of test configurations have been employed. In the first, the gas is expanded to atmospheric pressure through a converging-diverging nozzle and models are placed in the free jet of high temperature gases. This leads to high heat

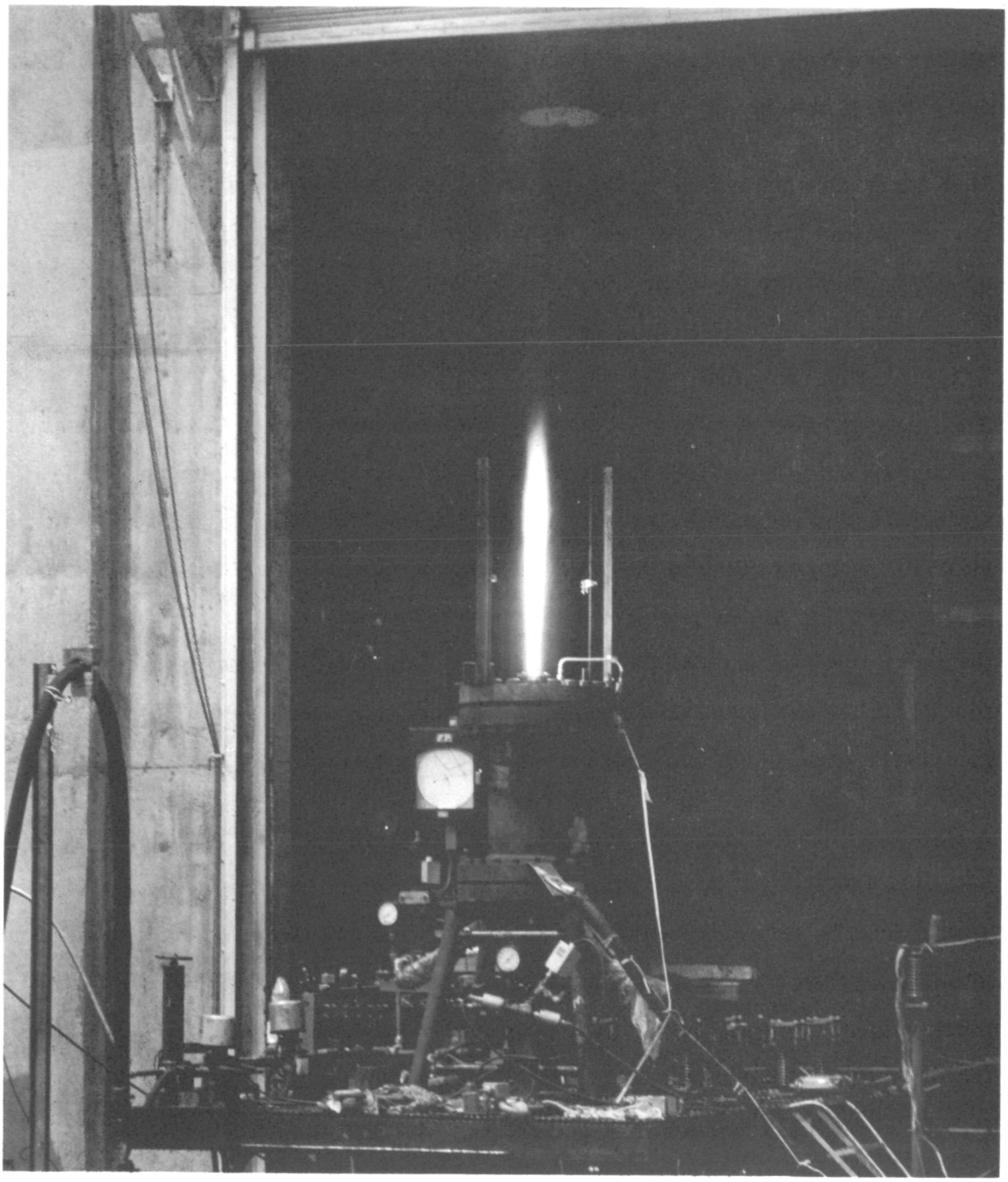

Figure B-81. Air arc in operation

transfer rate experiments (approximately 3000 Btu/sq ft - sec.) in a flow of moderate supersonic Mach number. The shroud nozzle technique has also been used for test purposes. Here a large scale model is inserted within a nozzle so that the flow area distribution leads to the desired pressure distribution.

1.3.4.7 SOLAR FURNACE

The image furnace consists of apparatus capable of producing steady state surface heating to 3500K on a 1/4-inch diameter specimen (3000K on a 1/2-inch diameter specimen) surrounded by a vacuum or controlled atmosphere of any desired composition. Two sources of thermal radiation can be employed. With a carbon arc source (Figure B-82, left), two 60-inch rhodium plated parabolic mirrors are opposed and aligned, the image of the arc, located at the focus of one parabola is projected and converged to focus at the test specimen located at the focal point of the other mirror. When engaging the sun as the source (Figure B-82, right), the maximum temperature noted above is obtainable. A heliostat (flat mirror), driven by automatic servo-mechanisms, follows the sun to permit continued radiation to be directed into the stationary parabola, again coming to focus on the test component.

Solar radiation is monitored by a pyrheliometer with recording equipment for continuous calibration. The thermal flux density attainable is approximately twice that with the arc source. The adjustment of an attenuator cylinder allows for flux variation and corresponding blackbody change in temperature down to 1400K.

Instrumentation available includes optical radiation pyrometers, spectroscopic equipment, thermocouple circuitry and calorimeter devices.

This equipment has been applied to investigations of radiative characteristics of metals, reactions of plastics over ranges of heat flux, and analysis of pyrolytic products of irradiated plastics.

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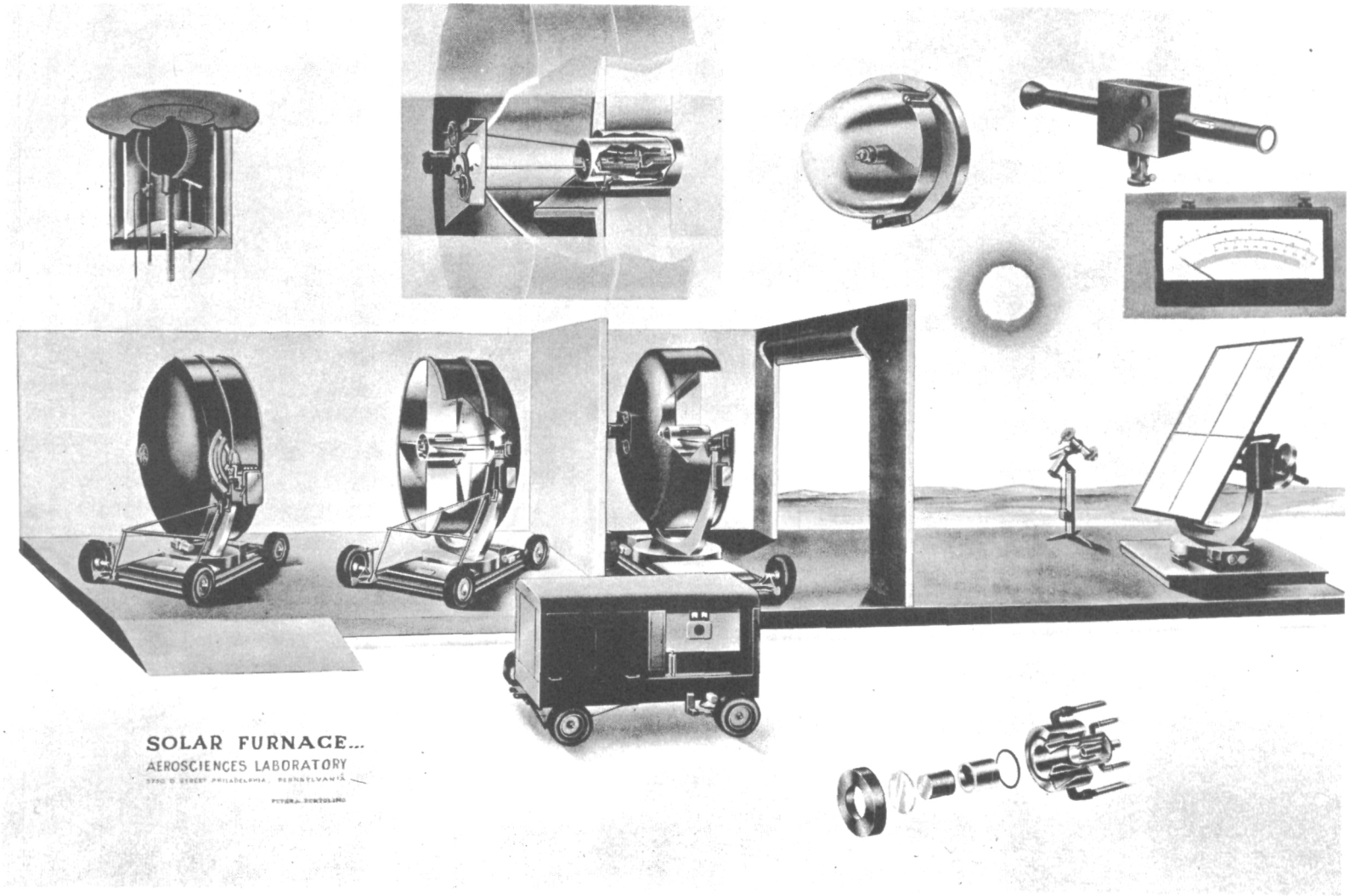

Figure B-82. Solar furnace

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1.3.5 Solar Test Facility

Figure B-83 shows the MSVD Solar Test Facility designed to be located at Phoenix, Arizona. It will be used to permit testing of solar concentrating systems.

The facility is equipped to automatically record daily climatological data such as wind velocity and direction, relative humidity, ambient temperature, and solar intensity.

An azimuth-elevation sun tracking platform is provided which is capable of handling parabolic mirrors up to 25 feet in diameter. The dynamic accuracy of the azimuth and elevation drive systems will be better than 0.05′degree at 5 revolutions per day and better than 0.05 degree at 90 degrees per 3 hours, respectively.

A unique feature of the solar energy facility is the movable insulated steel building in which the concentrator platform is housed. It is erected on a carriage which travels over an 80 foot long rail system at 20 feet per minute. Besides affording weather protection to the concentrator system, it provides the capability of simulating the sun to dark side cycling which solar space power systems will encounter in flight.

1.3.6 Radiation Laboratory and Facilities

The nuclear radiation facilities of the General Electric Company General Engineering Laboratory at Schenectady are available to MSVD for the investigation of problems in radiation technology which apply to the APOLLO program. These facilities include four particle accelerators, a 10,000-curie cobalt-60 irradiation vault, two multichannel and two single channel pulse-height analyzers, two radioisotope neutron sources, beta- and gamma-ray spectrometers (scintillation type), and ultrafast counting circuits. See Figures B-84 and B-85. These are supplemented by various types of ionization chambers, proportional counters, fission counters, Geiger counters, scintillation counters, and all the standard electronic equipment to be found in a well-equipped radiation laboratory.

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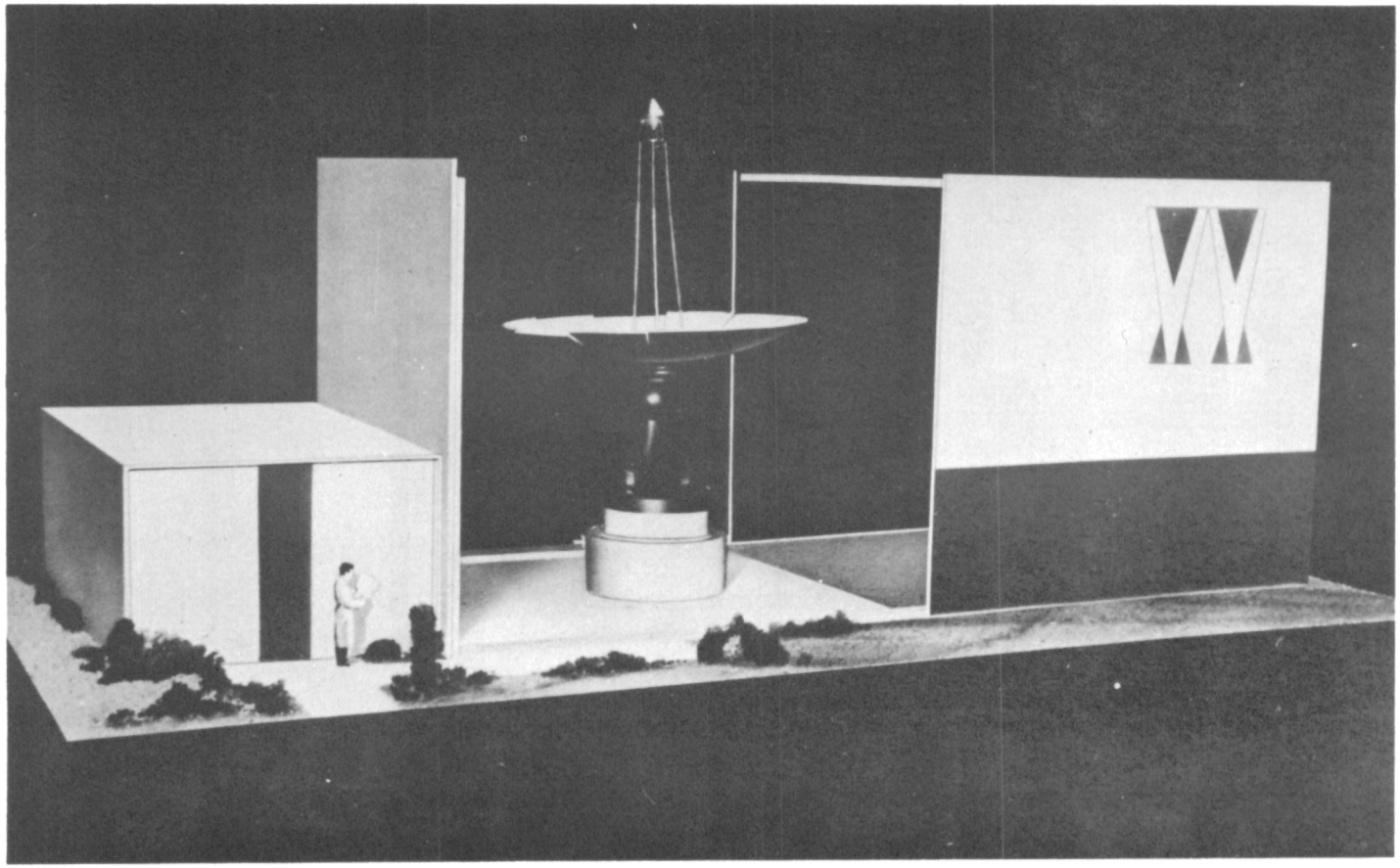

Figure B-83. MSVD solar test facility

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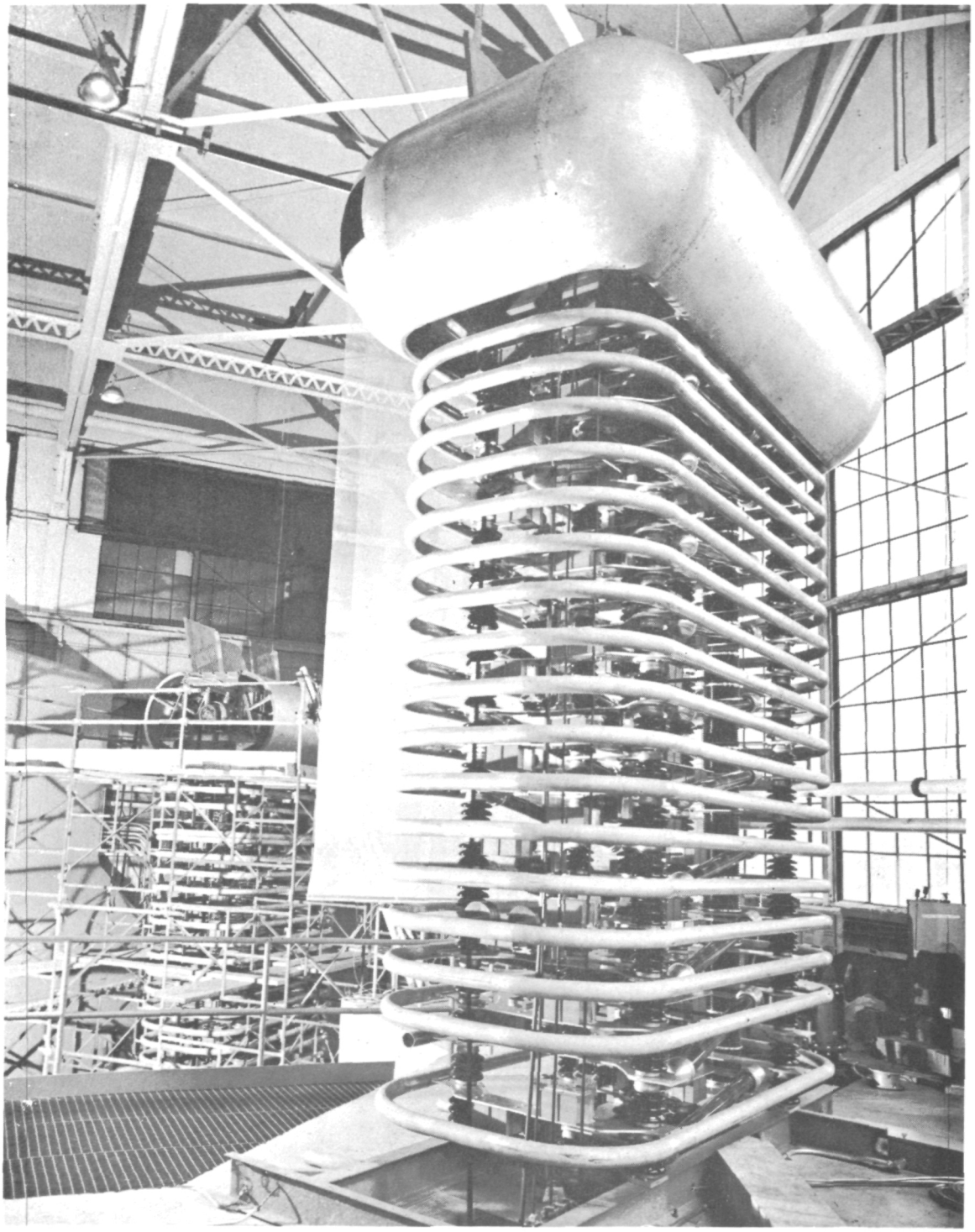

Figure B-84. Special radiation facilities, linear accelerator

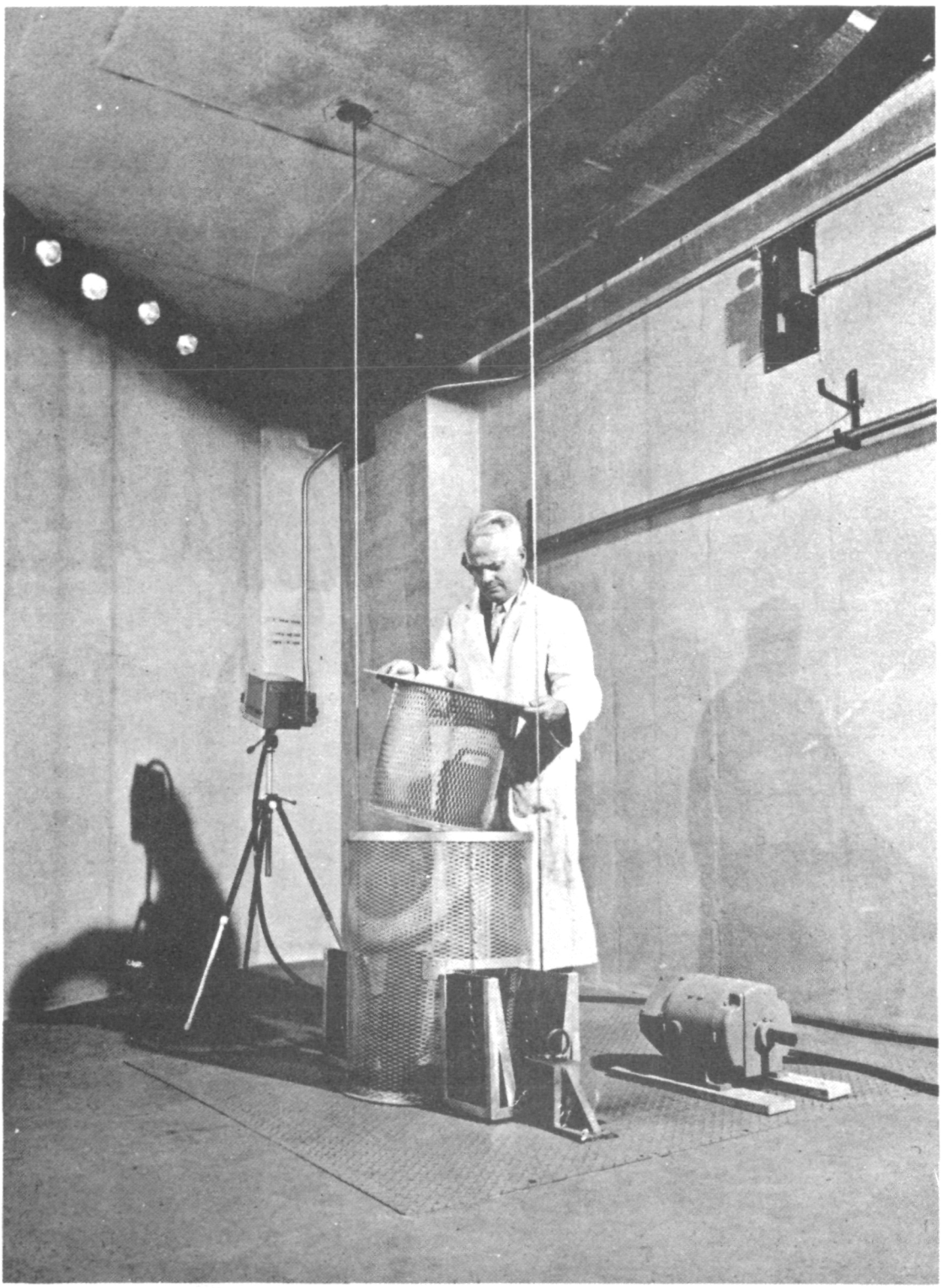

Figure B-85. Special radiation facilities, irradiation vault

One small irradiation vault is of particular interest to this project since it has the capability of combined environment testing simultaneously subjecting a test item to a vacuum of 10^{-6} mm Hg, radiation of 2 - 10,000 curies/hour, and temperature cycling using quartz lamp radiators. Samples as large as 15 inches in diameter and 15 inches long have been tested in this facility and it can easily be adapted to test items as large as 3 x 6 x 5 feet. It will be used in this program to perform combined environment tests, which are so vital to the measurement of reliability.

1.3.7 Environmental Test Facilities

In addition to the Space Simulators described in paragraph 1.3.2, MSVD has available the following environmental facilities for development and qualification testing.

1.3.7.1 ALTITUDE-TEMPERATURE-HUMIDITY CHAMBERS

Figure B-86 is a matrix of the various Altitude-Temperature-Humidity Chambers available at MSVD for system, subsystem and component testing. Figures B-87 through B-108 illustrate these chambers.

TEMPERATURE–HUMIDITY–ALTITUDE CHAMBERS

Type	Name	Size	Capacity
Temp-Hum-Alt.	American Research Co.	12x10x12 foot	Altitude: 0 to 100,000 feet Temp: -100 to 200 deg F. Hum: 20 to 90%
Temp-Hum-Alt.	Tenney Engineering Co. #64STR100350	4 x 4 x 4 foot	Altitude: 0 to 200,000 feet Temp: -100 to 350 deg F. Hum: 20 to 95%
Temp-Hum-Alt.	Tenny Engineering Co. #27STR100300	3 x 3 x 3 foot	Altitude: 0 to 200,000 feet Temp: -100 to 350 deg F. Hum: 20 to 95%

Type	Name	Size	Capacity
Temp-Hum-Alt.	Tenney Engineering Co. #18STR100350	2-1/2 x 2-1/2 x 3 foot	Altitude: 0 to 200,000 feet Temp: -100 to 350 deg F. Hum: 20 to 95%
Temp-Hum	Tenney Engineering Co. #64TR100200	4 x 4 x 4 foot	Temp: -100 to 200 deg F. Hum: 20 to 95%
Temp-Hum	Murphey Miller #H64	4 x 4 x 4 foot	Temp: 0 to 200 deg F. Hum: 5 to 98%
Temp-Hum	International Radiant #H253035	30 x 36 x 42 inch	Temp: 35 to 200 deg F. Hum: 20 to 95%
Temp-Hum	Conrad #FD1022	24 x 24 x 30 inch	Temp: -125 to 375 deg F. Hum: 20 to 95%
Temp-Hum	Standard Cabinet #LHH/8FS	24 x 24 x 24 inch	Temp: -100 to 400 deg F. Hum: 20 to 95%
Temp-Hum	Tenney Engineering Co. #8TR100250	24 x 24 x 24 inch	Temp: -100 to 250 deg F. Hum: 20 to 95%
Temp-Hum	Bowser #1158	16 x 17-1/2 x 22 inch	Temp: ambient to 180 deg F. Hum: 20 to 95%
Temp.	American #5064-100350	4 x 4 x 4 foot	Temp: -100 to 350 deg F.
Temp.	Trent #H303054	30 x 30 x 54 inch	Temp: ambient to 2000 deg F.
Temp.	Tenney 8T100400	24 x 24 x 24 inch	Temp: -100 to 400 deg F.
Temp.	International Radiant #VS100T20C	24 x 24 x 24 inch	Temp: -100 to 350 deg F.
Temp.	General Electric #AD36	24 x 24 x 24 inch	Temp: ambient to 750 deg F.

Type	Name	Size	Capacity
Temp.	Tenney #TSA-9-100	22 x 40 x 18 inch	Temp: ambient to 100 deg C.
Temp.	Precision #1052	17 x 19 x 18 inch	Temp: ambient to 180 deg C.
Temp.	Precision #1058	11 x 13 x 14 inch	Temp: ambient to 260 deg F.
Temp.	American Type Z	18 x 15-1/2 x 19 inch	Temp: -100 to 200 deg F.
Temp.	Precision #1071	11 x 13 x 14 inch	Temp: ambient to 180 deg C.
Temp.	Tenney #TMUF 1.5-100350	14 x 14 x 14 inch	Temp: -100 to 350 deg F.
Temp.	Electric Hotpads #7075	12 x 12 x 11 inch	Temp: 100 to 1000 deg F.

Figure B-86. MSVD temperature-humidity-altitude chambers.

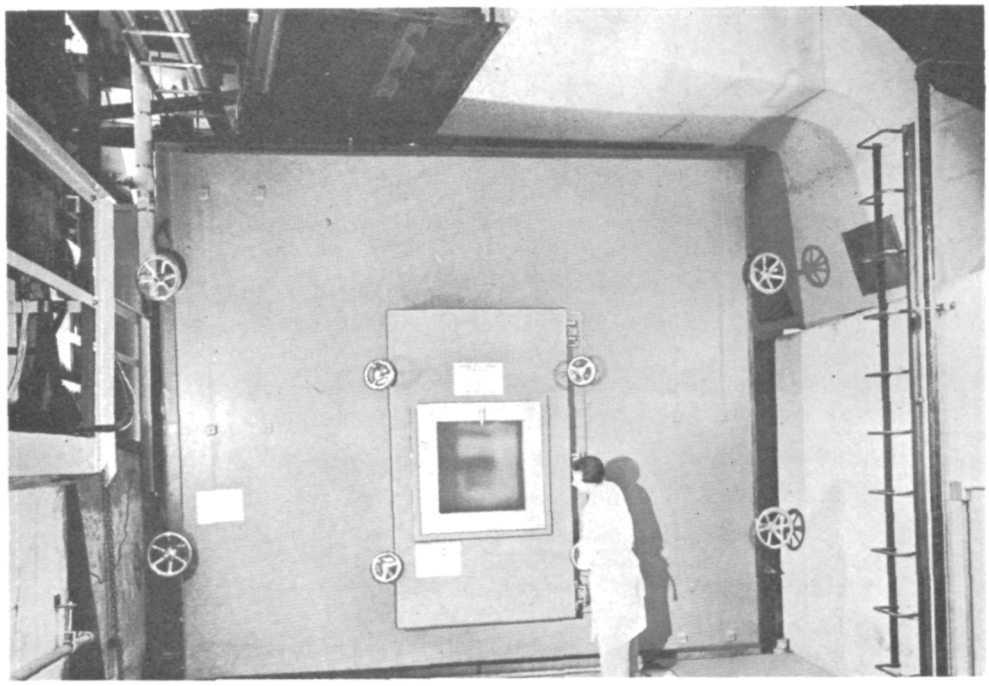

Figure B-87. 12 x 10 x 12 foot American alt-temp-hum. chamber

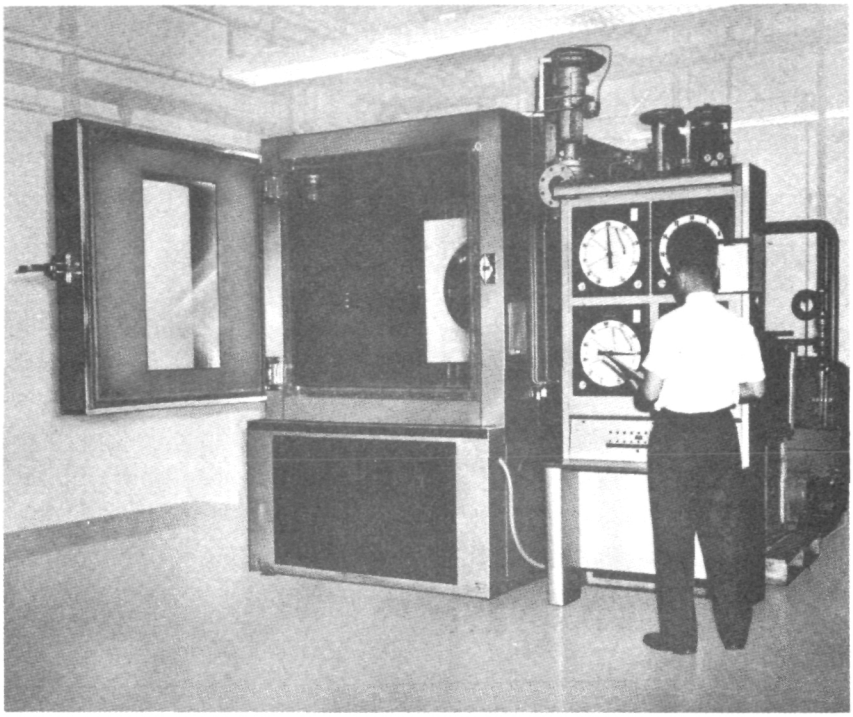

Figure B-88. Tenney 4 x 4 x 4 foot alt-temp-hum. chamber

Figure B-89. Tenney 3 x 3 x 3 foot alt-temp-hum. chamber

Figure B-90. Tenney 2-1/2 x 2-1/2 x 3 foot alt-temp-hum. chamber

Figure B-91. Tenney 4 x 4 x 4 foot temp-hum. chamber

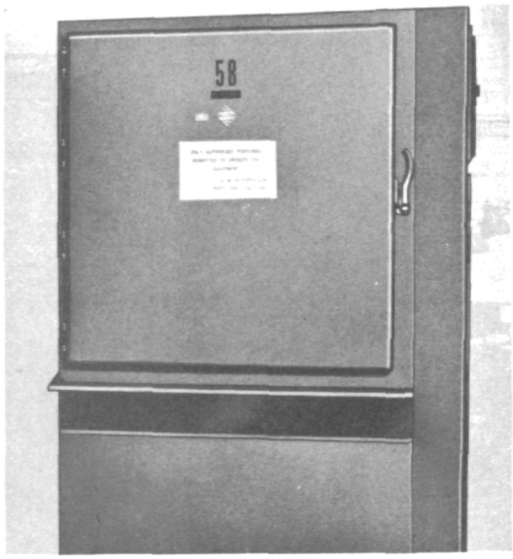

Figure B-92. Murphey Miller 4x4x4 foot temp-hum. chanber

Figure B-93. International Radiant 30 x 36 x 42 inch temp-hum. chamber

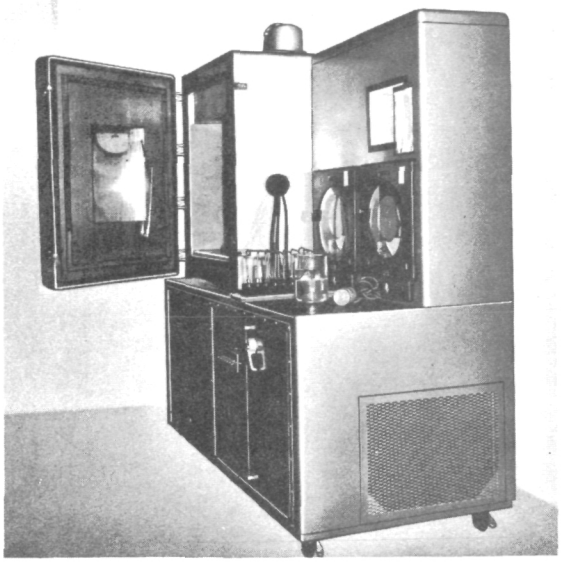

Figure B-94. Conrad 24 x 24 x 30 inch temp-hum. chamber

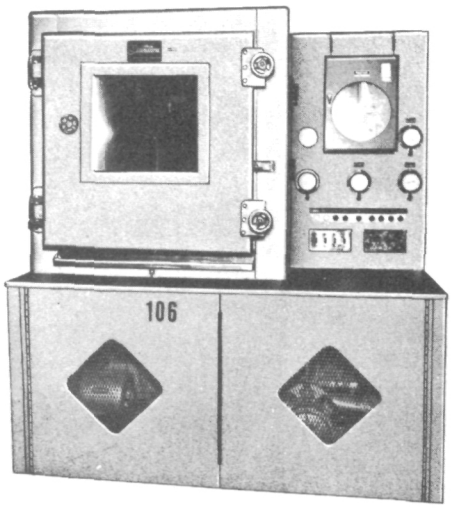

Figure B-95. Standard cabinet 24 x 24 x 24 inch temp-hum. chamber

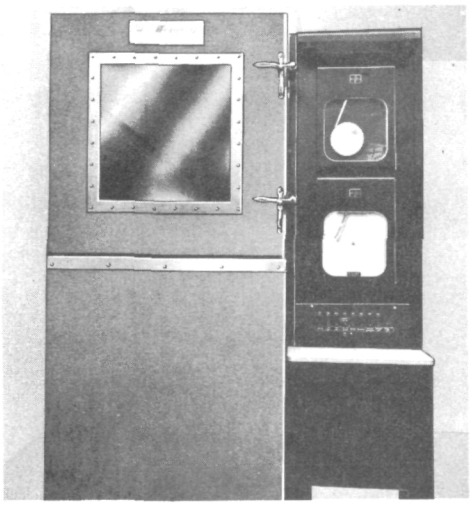

Figure B-96. Tenney 24 x 24 x 24 inch temp-hum. cabinet

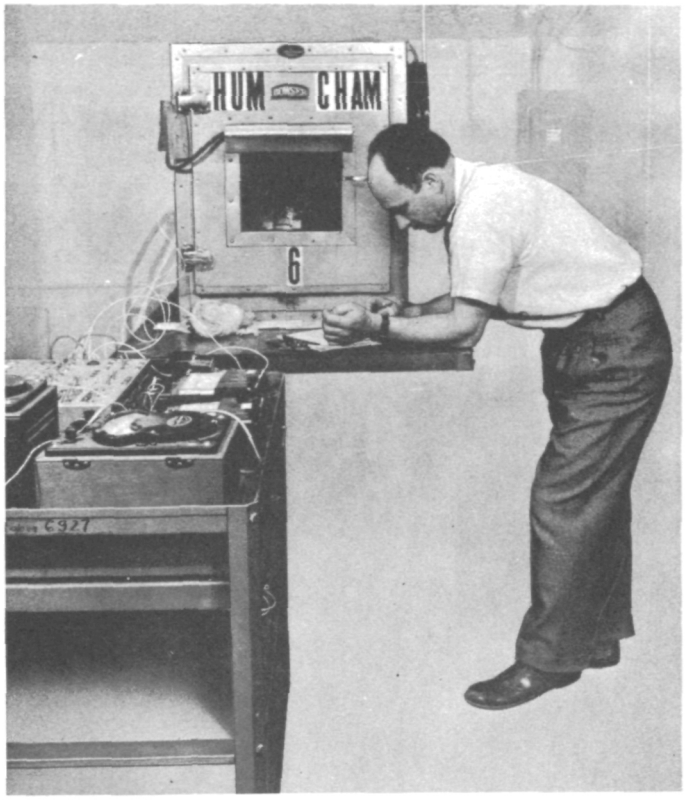

Figure B-97. Bowser 16 x 17-1/2 x 22 inch temp-hum. cabinet

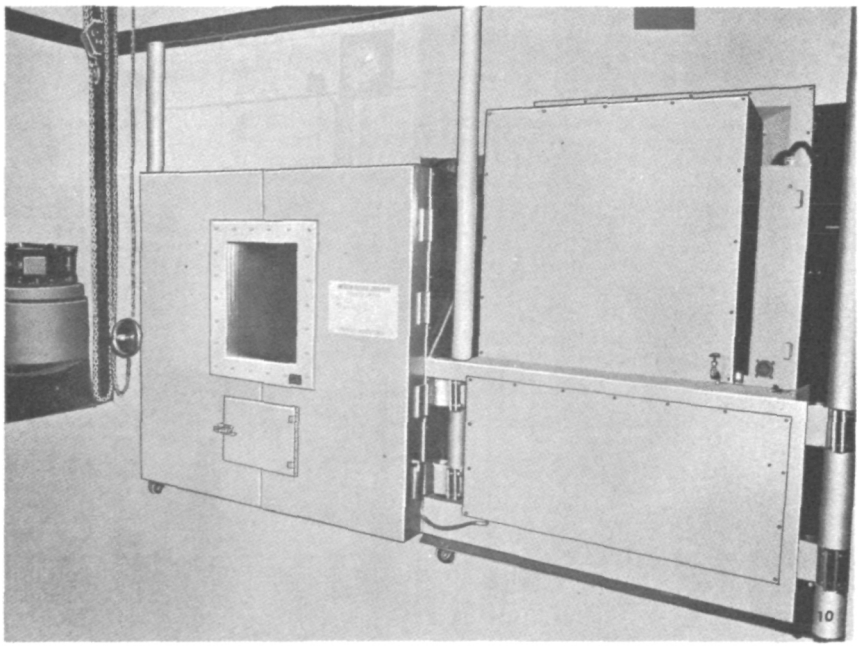

Figure B-98. American 4 x 4 x 4 foot temperature chamber

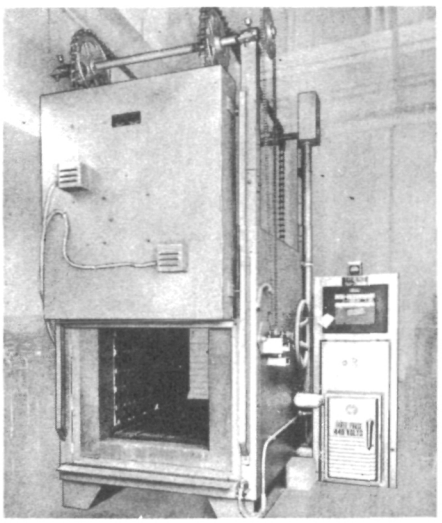

Figure B-99. Trent 30 x 30 x 54 inch temperature oven (2000 F)

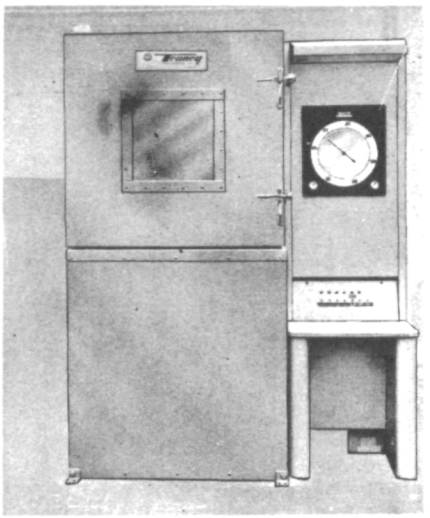

Figure B-100. Tenney 24 x 24 x 24 inch temperature chamber

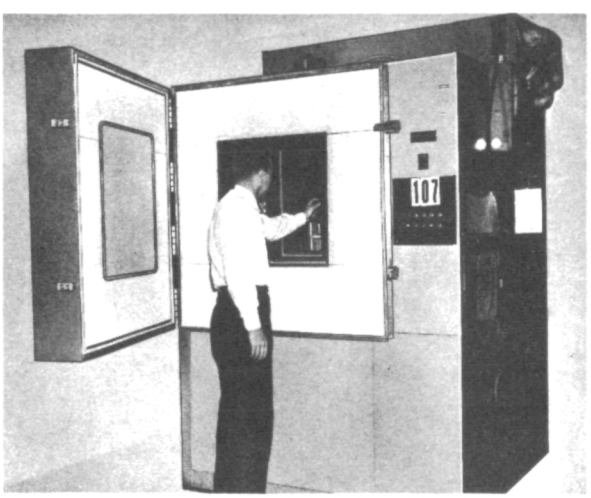

Figure B-101. International Radiant 24 x 24 x 24 inch temperature chamber

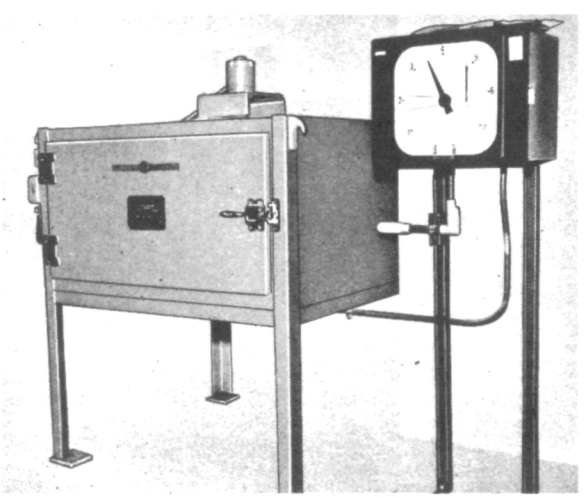

Figure B-102. General Electric 24 x 24 x 24 inch temperature chamber

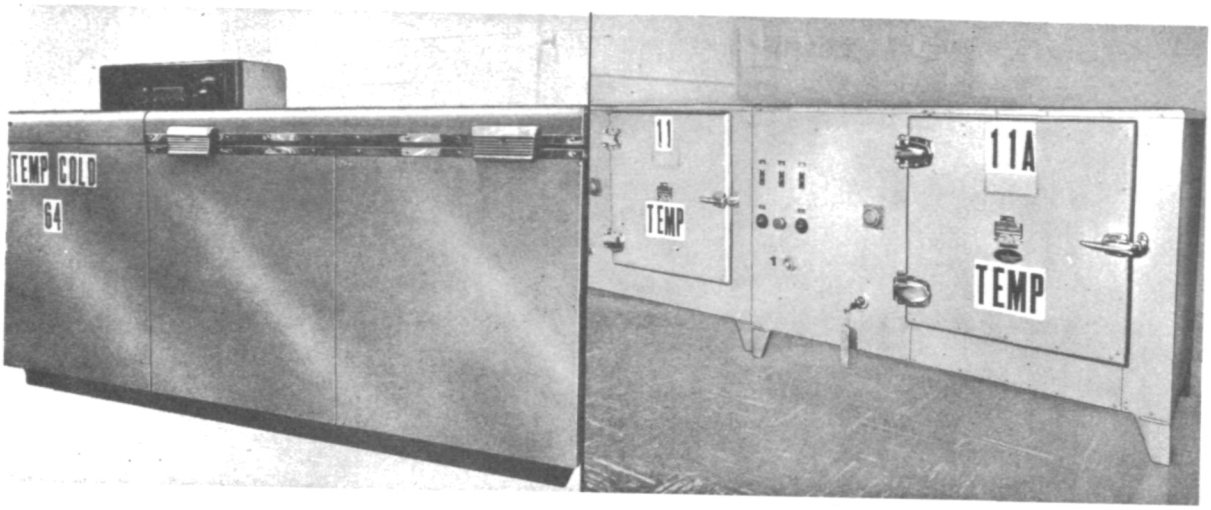

Figure B-103. Tenney 22 x 40 x 18 inch temperature chamber

Figure B-104. Precision 17 x 19 x 18 inch temperature chambers (left) and 11 x 13 x 14 inch temperature chamber (right)

Figure B-105. American 18 x 15-1/2 x 19 inch temperature chamber

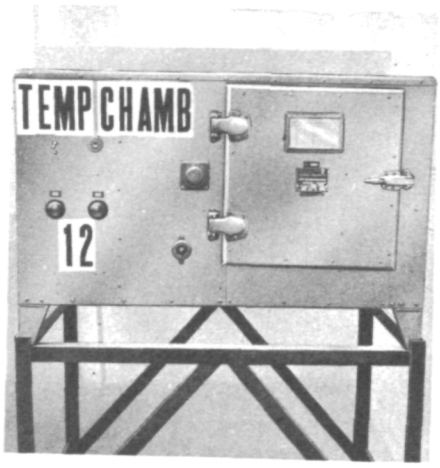

Figure B-106. Precision 11 x 13 x 14 inch temperature chamber

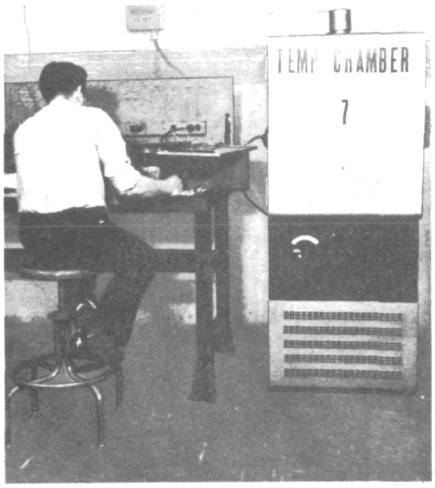

Figure B-107. Tenney 14 x 14 x 14 inch temperature chamber

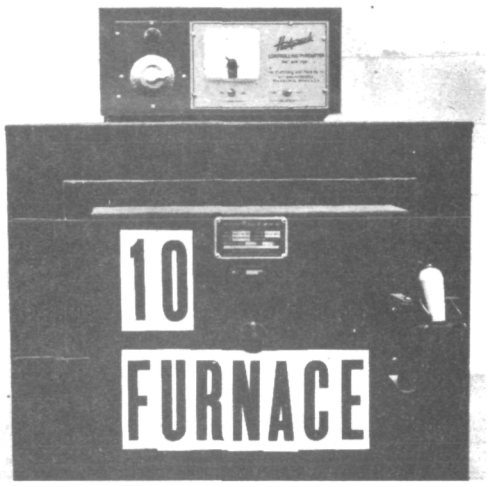

Figure B-108. Electric hotpack 12 x 12 x 11 inch temperature chamber

1.3.7.2 THERMAL SHOCK FACILITY

Figure B-109 is a radiant oven used for testing structures and materials for thermal shock in connection with theromdynamic studies and hardware development.

1.3.7.3 VIBRATION TEST EQUIPMENT

Figure B-110 is a matrix of the various vibration equipments available at MSVD for system, subsystem and component testing. Figures B-111 through B-120 illustrate these machines.

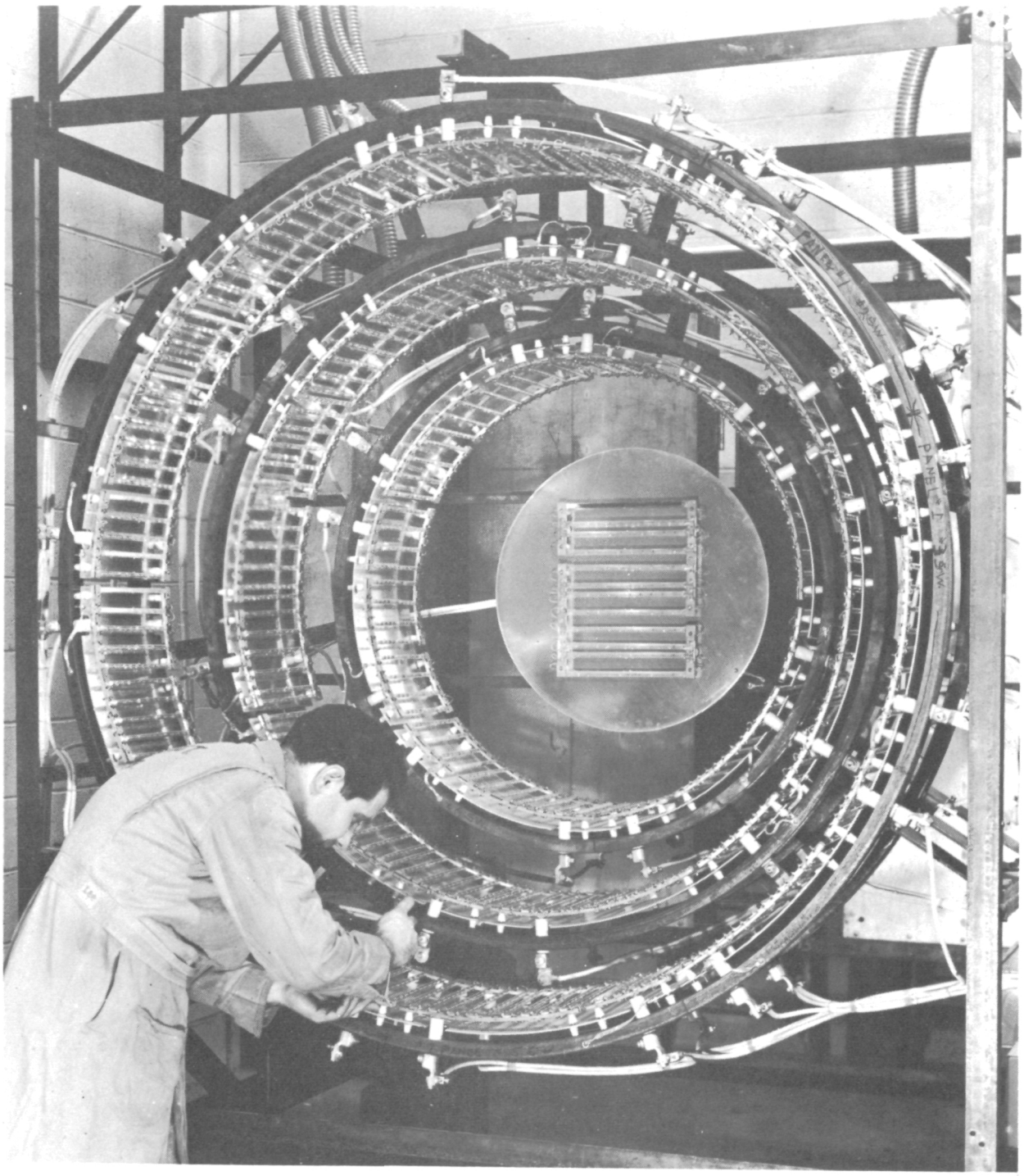

Figure B-109. Radiant oven for thermal shock tests

MSVD VIBRATION TEST EQUIPMENT

Name	Platform Size	Frequency in cps	Rating	Maximum Weight Capacity in pounds
MB #C200 Vibration Test System	30 inch dia.	5 to 2000	15, 000 lb	4, 000
LAB #RVH30-300 Reaction Vibration Table	30 x 30 inch	10 to 100	10 g at	300
American #100HL Vibration Table	15 x 18 inch	0 to 60	10 g at	100
MB #C100 Vibration Test System	27 inch dia.	5 to 2000	15, 000 lb	100
MB #C70 Vibration Test System	17 inch dia.	5 to 2000	7, 000 lb	70
Calidyne #A-174 Vibration Test System	6 x 6 inch	5 to 3500	1, 500 lb	–
LAB #10000 SVMCT-12 Vibration Package Tester	8 x 12 feet	2-2/3 to 5	1-1/4 g at	10, 000
Calidyne #C-88 Vibration Test System	3-1/2 x 3-1/2 inch	5 to 2000	100 lb	–
MB #C-1 Vibration Exciter	2 inch dia.	5 to 2000	50 lb	–
MB #C25H Vibration Test System	17 inch dia.	5 to 2000	3, 500 lb	–

Figure B-110. MSVD vibration test equipment

Figure B-111. MB #C200 two ton vibration machine

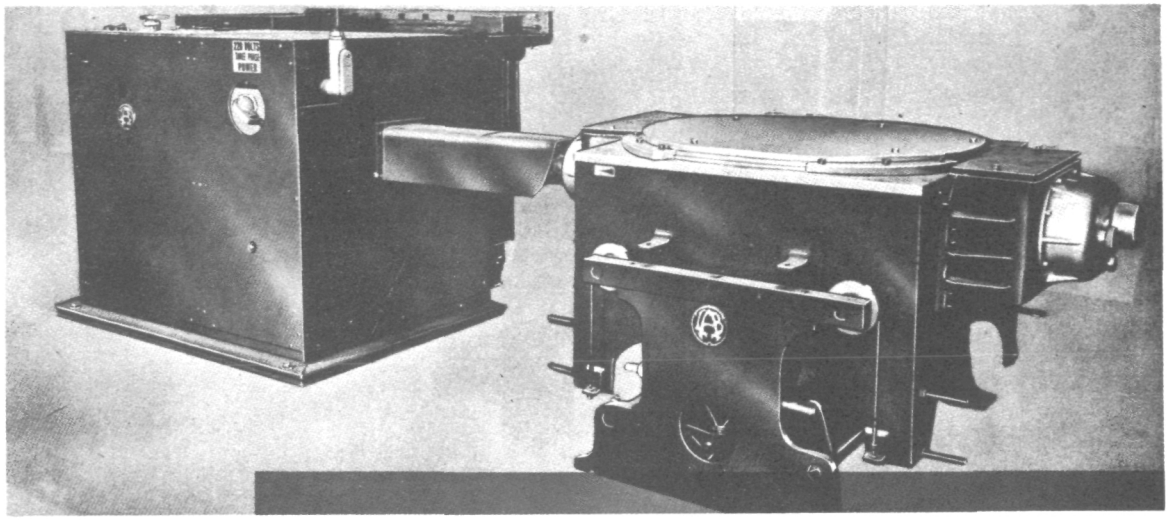

Figure B-112. LAB #RVH30-300, 300 lb reaction vibration table

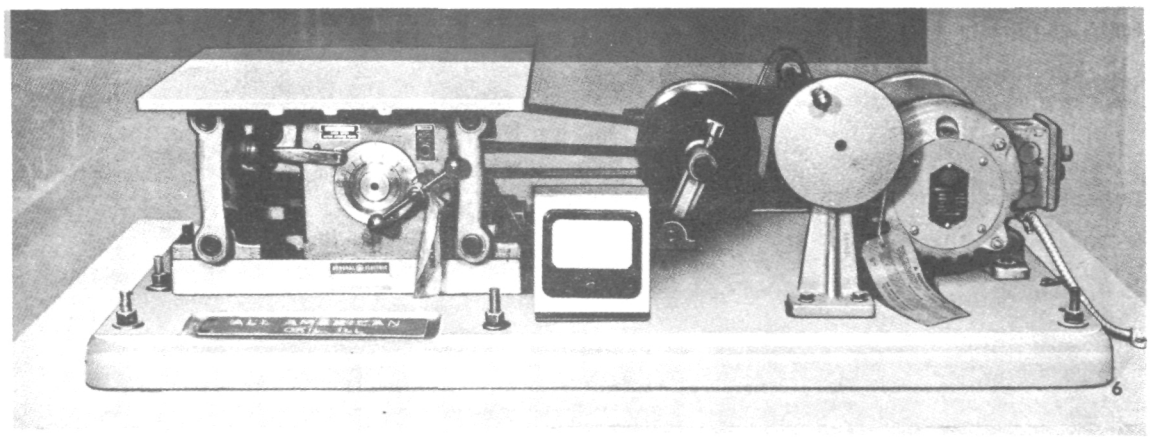

Figure B-113. American #100HL, 100 lb vibration table

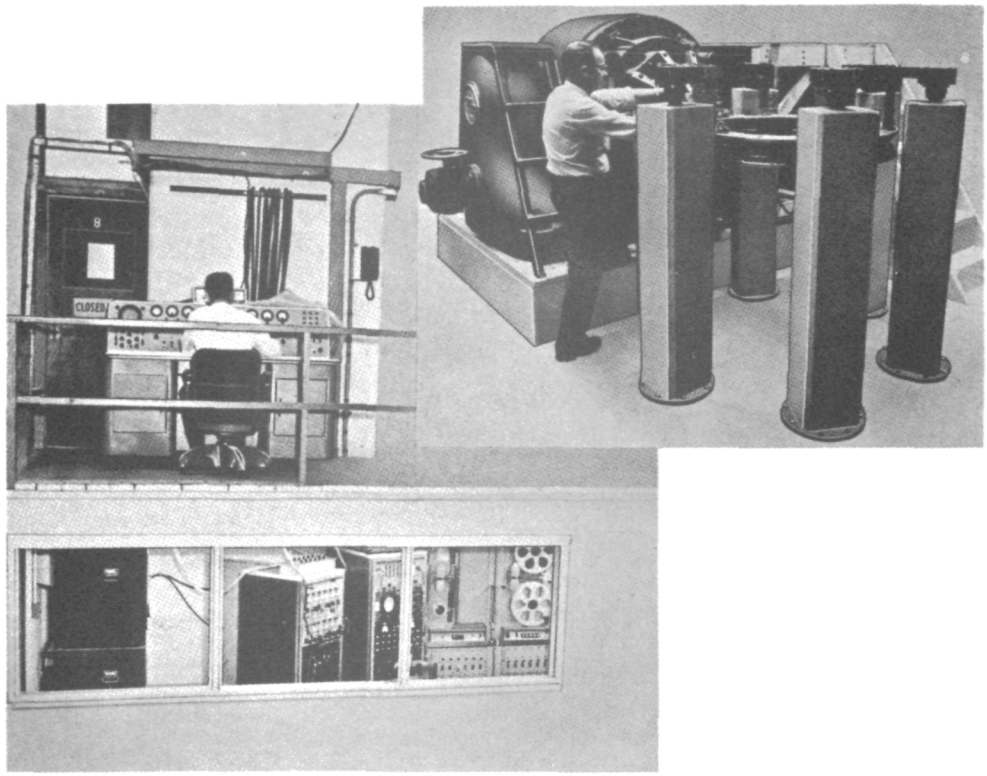

Figure B-114. MB #C100, 100 lb vibration test system

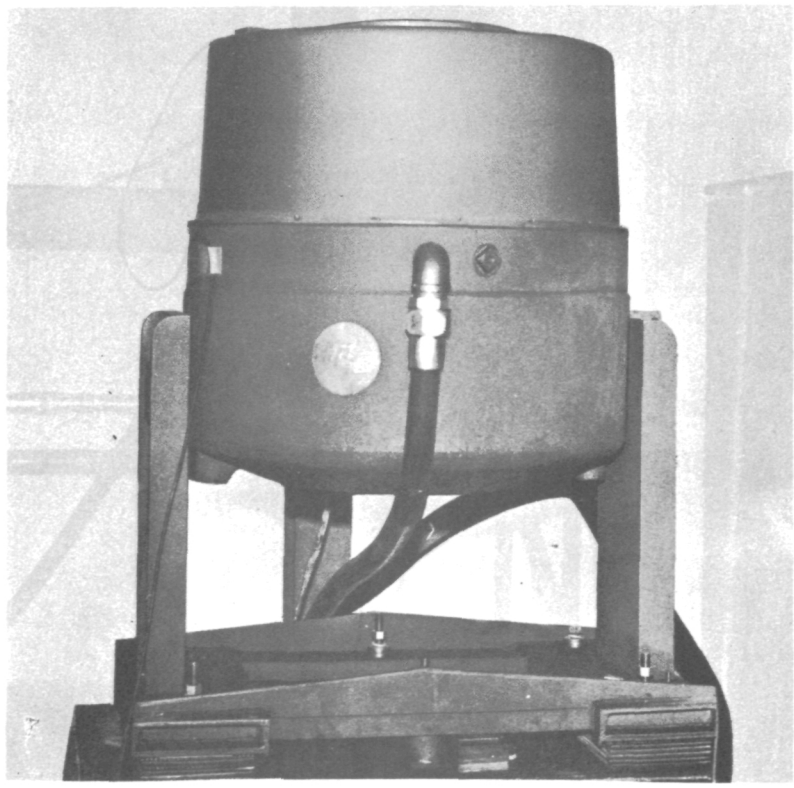

Figure B-115. MB #C70, 70 lb vibration test system

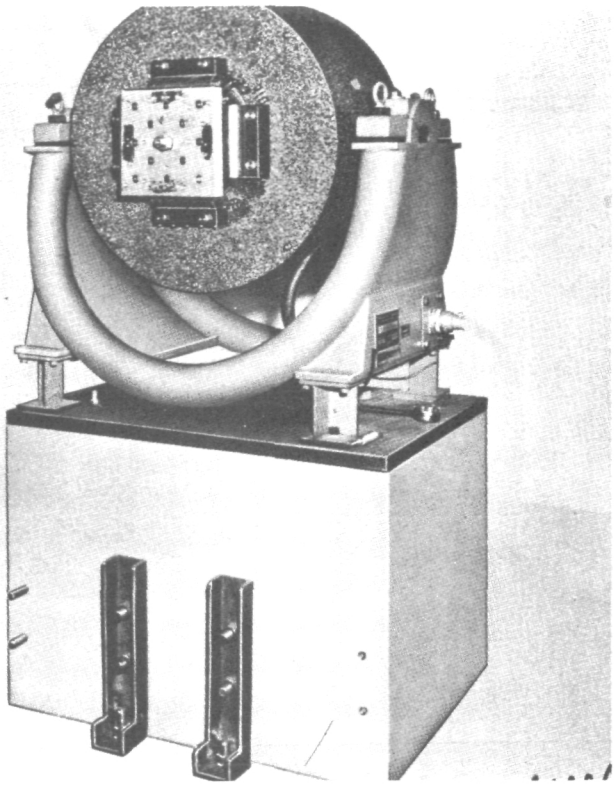

Figure B-116. Calidyne #A-174, vibration test system

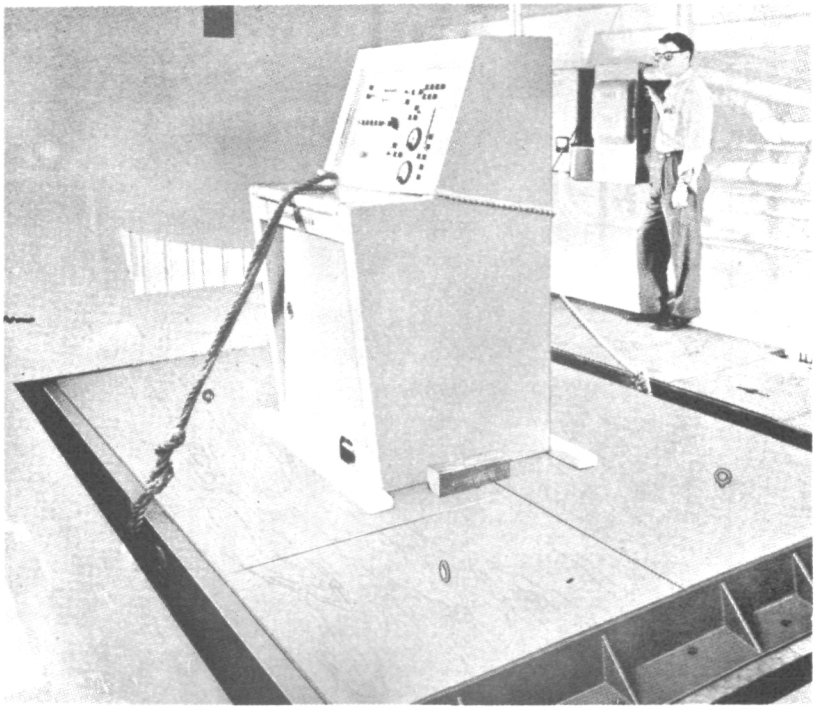

Figure B-117. LAB #10,000 SVMCT-12, 10,000 lb vibration package tester

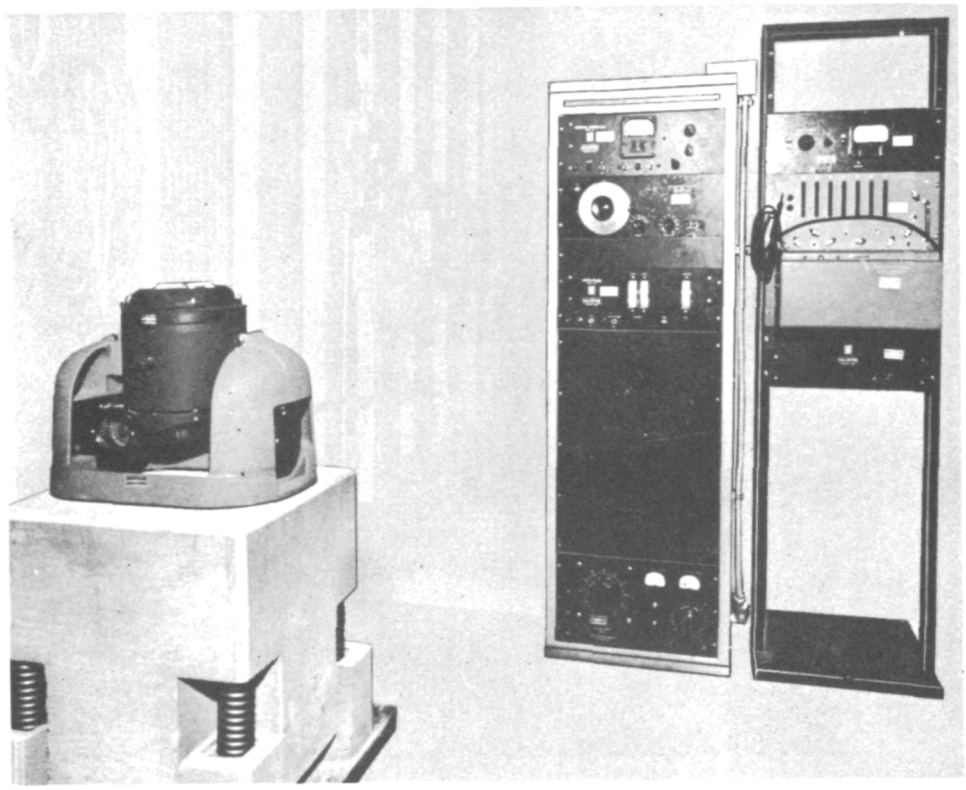

Figure B-118. Calidyne #C-88, vibration test system

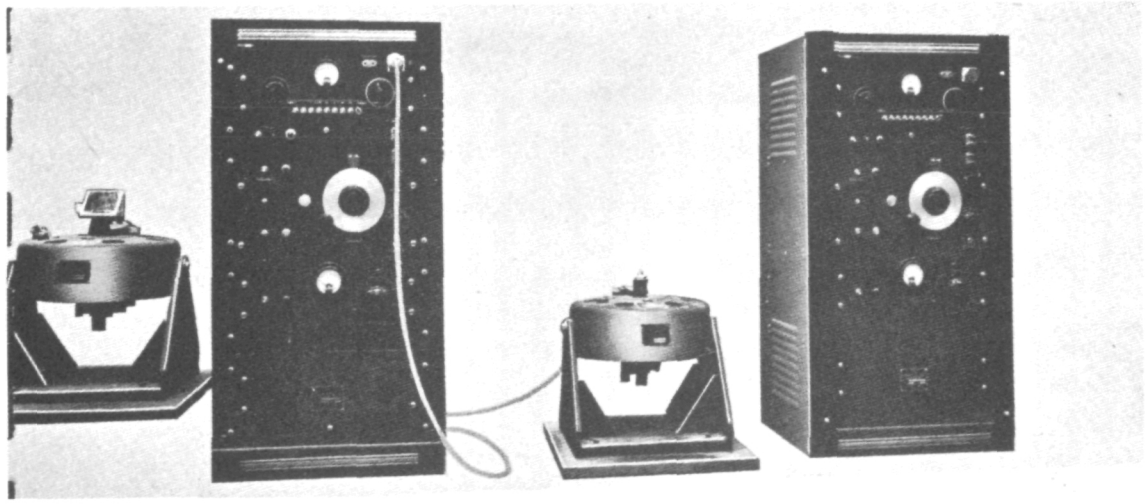

Figure B-119. MB #C-1 vibration exciter

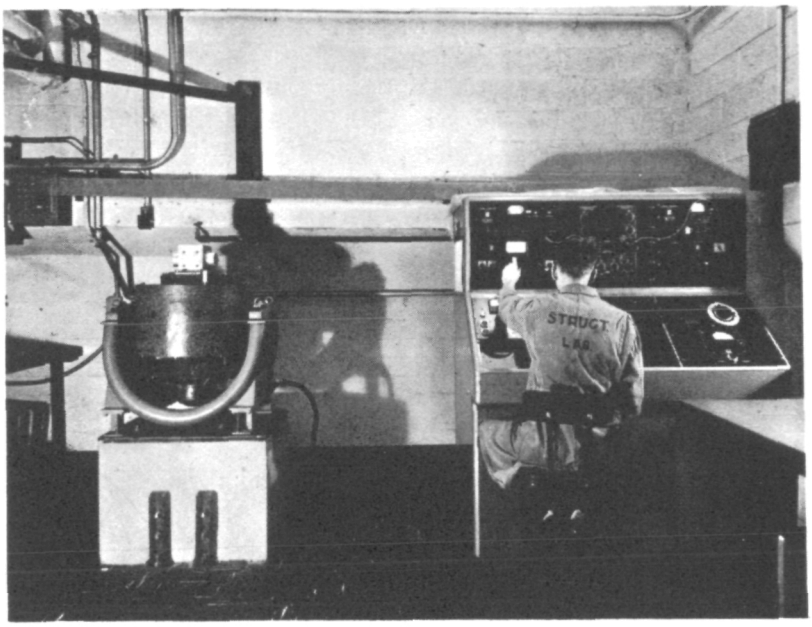

Figure B-120. MB #25H vibration test system

1.3.7.4 SHOCK TEST MACHINES

Figure B-121 is a matrix of the various shock test machines available at MSVD for system, subsystem and component testing. Figures B-122 through B-125 illustrate these machines.

MSVD SHOCK TEST MACHINES

Name	Maximum Load in Pounds	Maximum Specimen Size	Maximum Rating	Wave Shapes
Barry #150-400 VD Impact Tester	400	30 x 30 x 30 inch	1000 g	
Consolidated #A909A Hyge Actuator	—	19 x 31 inch	40,000 lb	Square, quarter sine, saw tooth, half sine, controlled inpact.
New England #DI-50 Drop Impact Shock Machine	50	10 x 15 x 13 inch	300 g	Half Sine
New England #DI-4 Shock Test Machine	4	6 x 5 x 5 inch	1000 g	
JAN S-44	4	4 x 8 inch	12 inch drop	Half Sine
SL-20	50	10 x 10 inch	20 foot drop	Variable
SL-100		(Elevator Shaft)	100 foot drop	Variable

Figure B-121. MSVD shock test machines

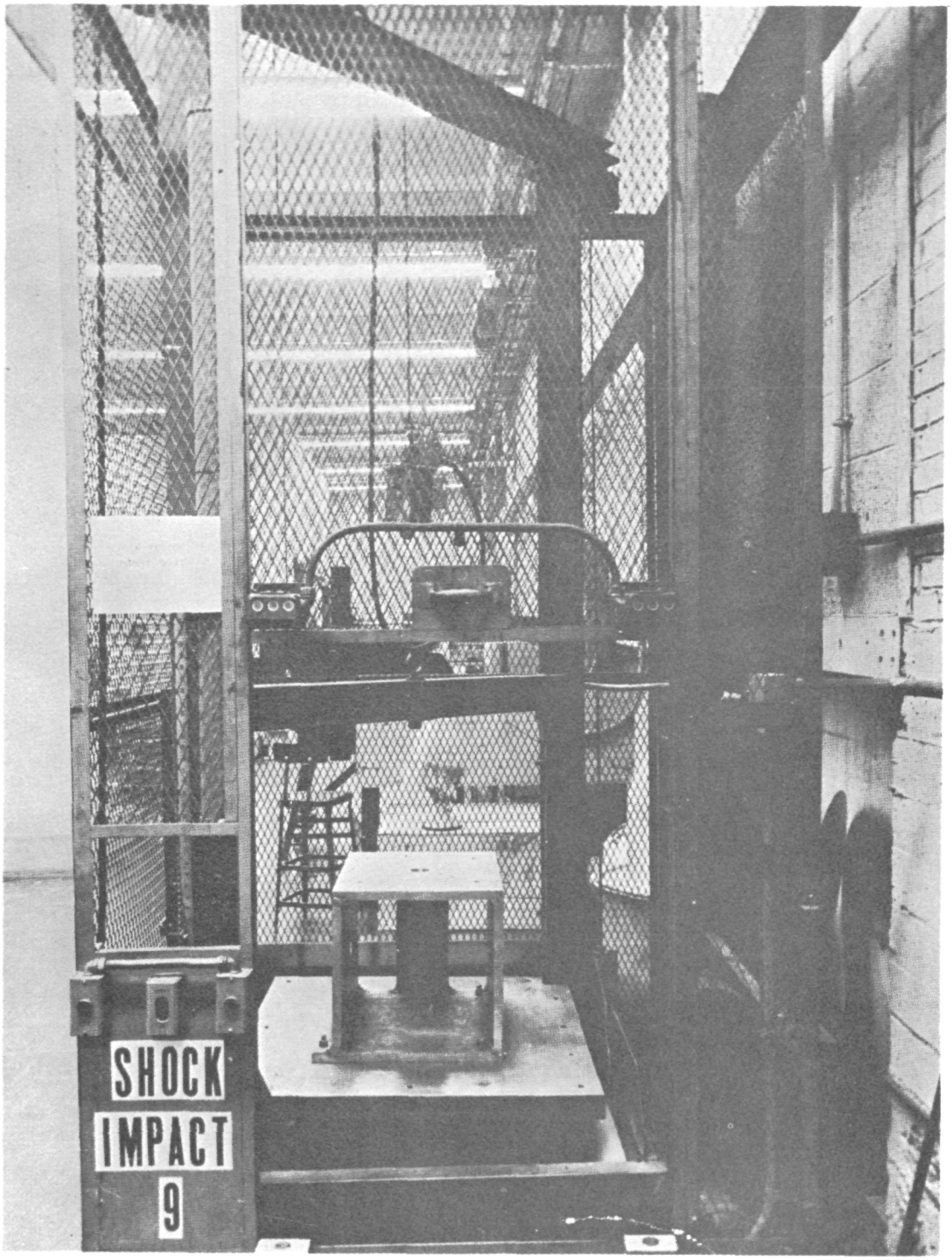

Figure B-122. Barry 150-400VD, 400 lb, 100 g shorck test machine

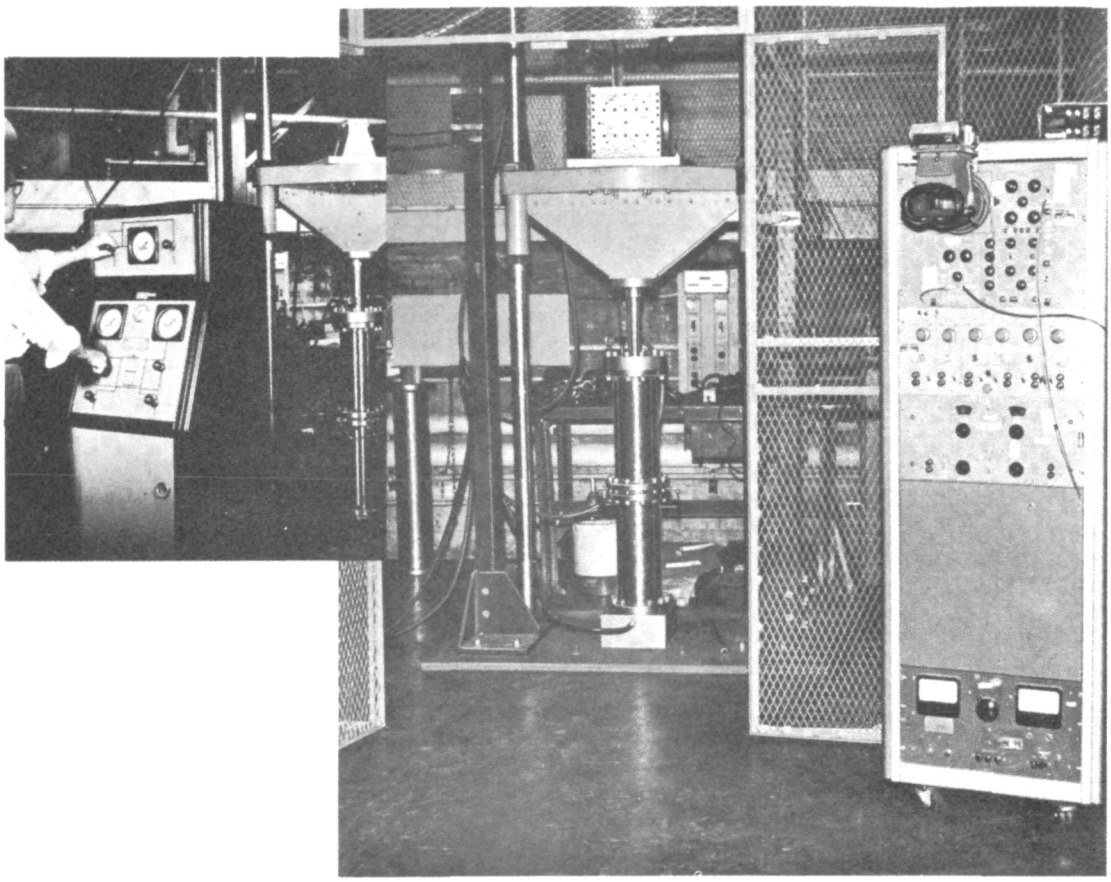

Figure B-123. Consolidated #A909A, 40,000 lb huge actuator

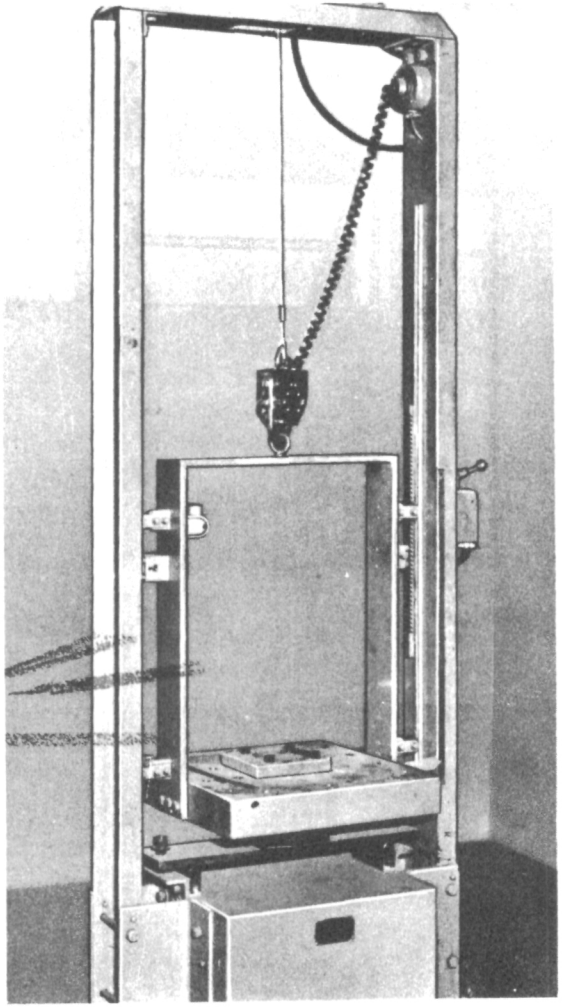

Figure B-124. New England #DI-50, 50 lb, 300 g drop impact shock machine

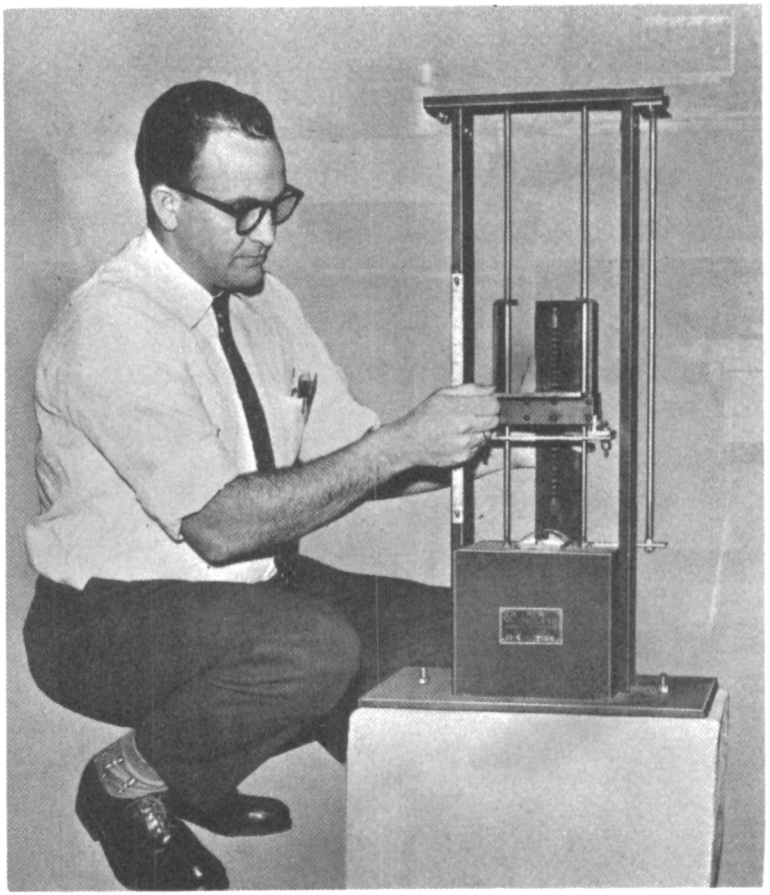

Figure B-125. New England #DI-4, 4 lb, 100 g shock test machine

1.3.7.5 ACCELERATORS

Figure B-126 is a matrix of the various accelerators available at MSVD for system, subsystem and component testing. Figures B-127 through B-130 illustrate some of these machines.

MSVD ACCELERATORS

Name	Maximum Load in pounds	Specimen Size	Rating
Genisco #E-185	500	30 x 30 x 24 inch	30,000 g - lb
Genisco #C-181	100	–	–
Genisco #C-159	100	24 x 24 x 18 inch	2,000 g - lb
Genisco #D-184	10	–	800 g - lb
Genisco #B-78	25	8 x 8 x 8 inch	1,200 g - lb

Figure B-126. MSVD accelerators

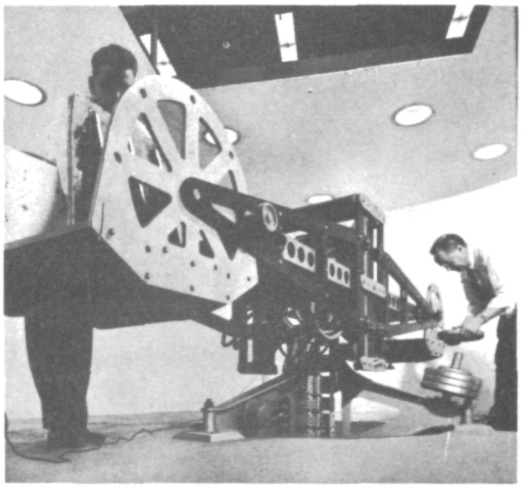

Figure B-127. Genisco #E-185, 500 lb accelerator

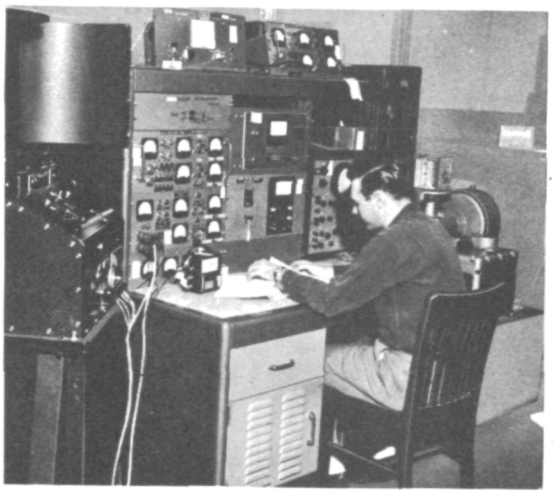

Figure B-128. Genisco #C-181, 100 lb, accelerator

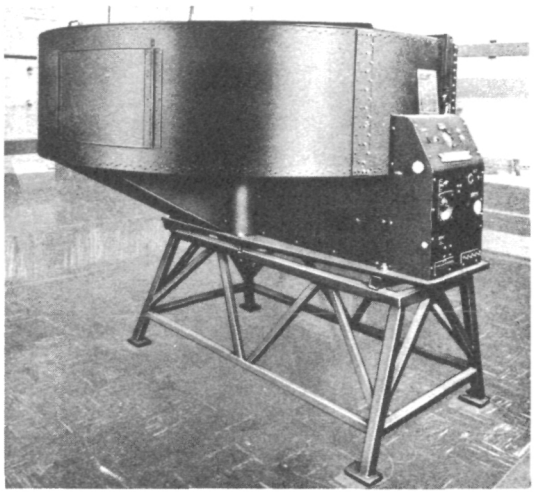

Figure B-129. Genisco #C-159, 100 lb, accelerator

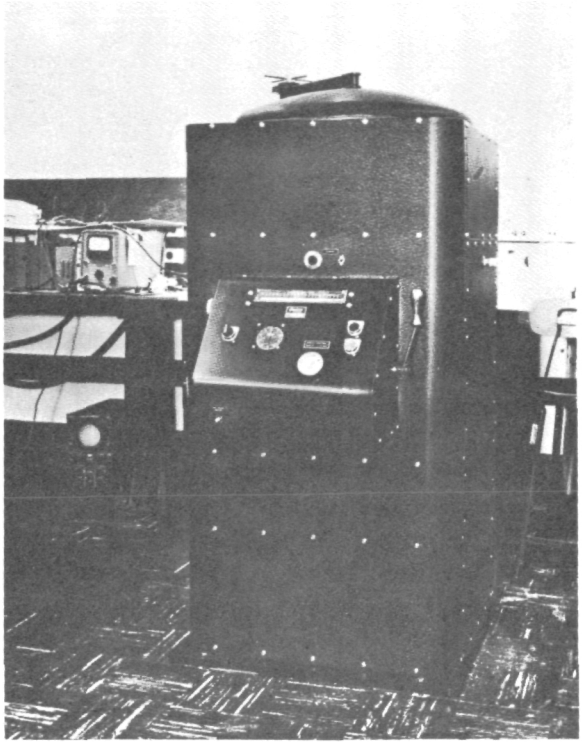

Figure B-130. Genisco #B-78, accelerator

1.3.7.6 RAIN, SUNSHINE, SALT SPRAY, FUNGUS, SAND AND DUST CHAMBERS

Figure B-131 is a matrix of various rain, sunshine, salt spray, sand and dust chambers available at MSVD for system, subsystem and component testing. Figures B-132 through B-138 illustrate some of these chambers.

Type	Name	Size	Rating
Rain	International Radiant #R64	4 x 4 x 4 ft	Temp: ambient to 125 F. Rain: 4 inch per hour
Rain & Sunshine	American Research #453	9 x 9 x 12 ft	Temp: ambient to 125 F. Rain: 4 inch per hour
Sunshine	International Radiant #6455	4 x 4 x 4 ft	Temp: ambient to 125 F.

Type	Name	Size	Rating
Sand & Dust	Environmental Equipment #SD64	4 x 4 x 4 ft	Temp: 25 to 71 C Hum: under 30% Dust: 0.1 to 0.5 gms/cu ft of air Air Vel: 300 to 2300 FPM.
Salt Spray	International Radiant #452	9 x 9 x 12 ft	Temp: ambient to 125 F.
Salt Spray	International Radiant #5540	4 x 4 x 4 ft	Temp: ambient to 125 F.
Fungus	International Radiant	9 x 9 x 12 ft	Temp: 35 to 180 F Hum: 20 to 95%
Fungus	Environmental Equipment #F64	4 x 4 x 4 ft	Temp: ambient to 125 F. Hum: 85 to 95%

Figure B-131. MSVD rain, sunshine, salt spray, sand and dust chambers

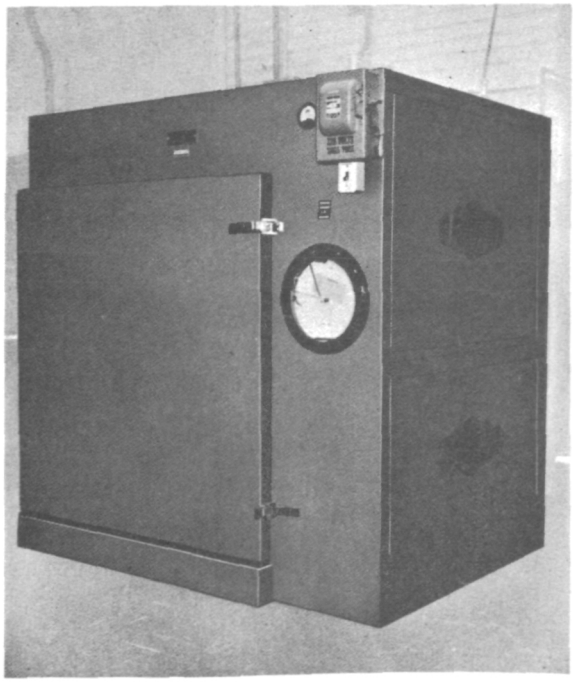

Figure B-132. International Radiant 4 x 4 x 4 foot rain chamber

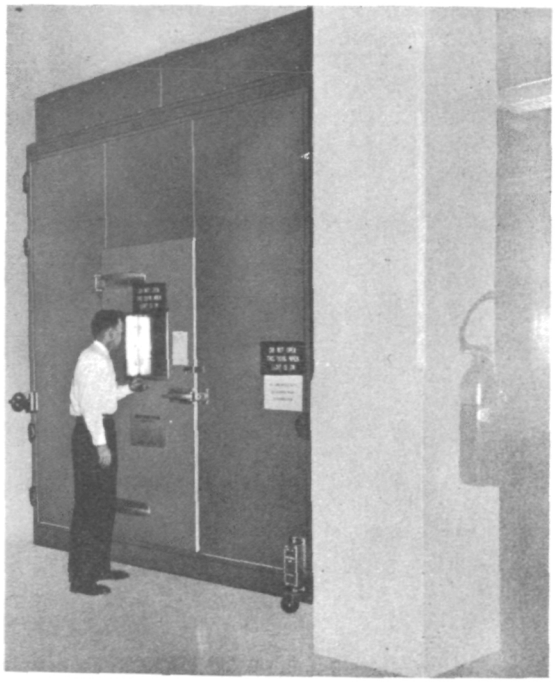

Figure B-133. American Research 9 x 9 x 12 foot rain and sunshine chamber

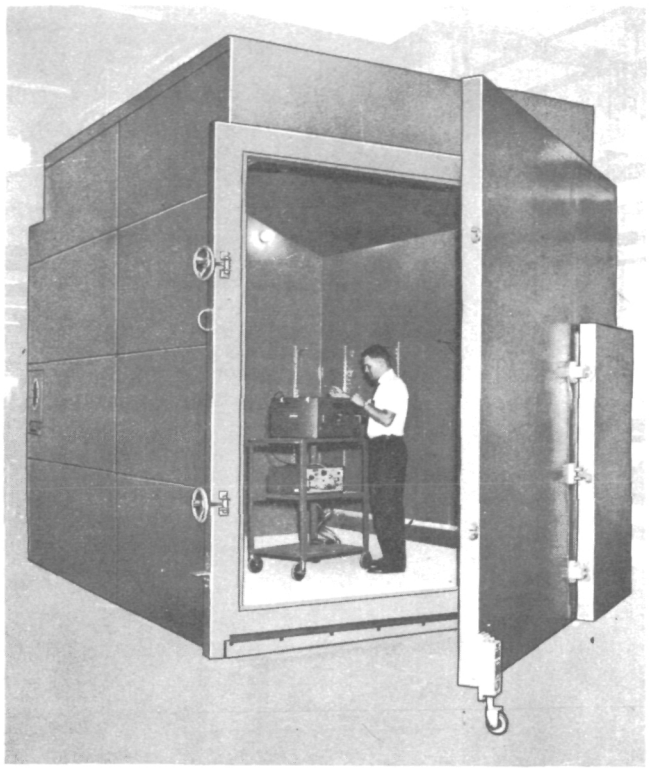

Figure B-134. International Radiant 9 x 9 x 13 foot salt spray chamber

Figure B-135. International Radiant 4 x 4 x 4 foot salt spray chamber

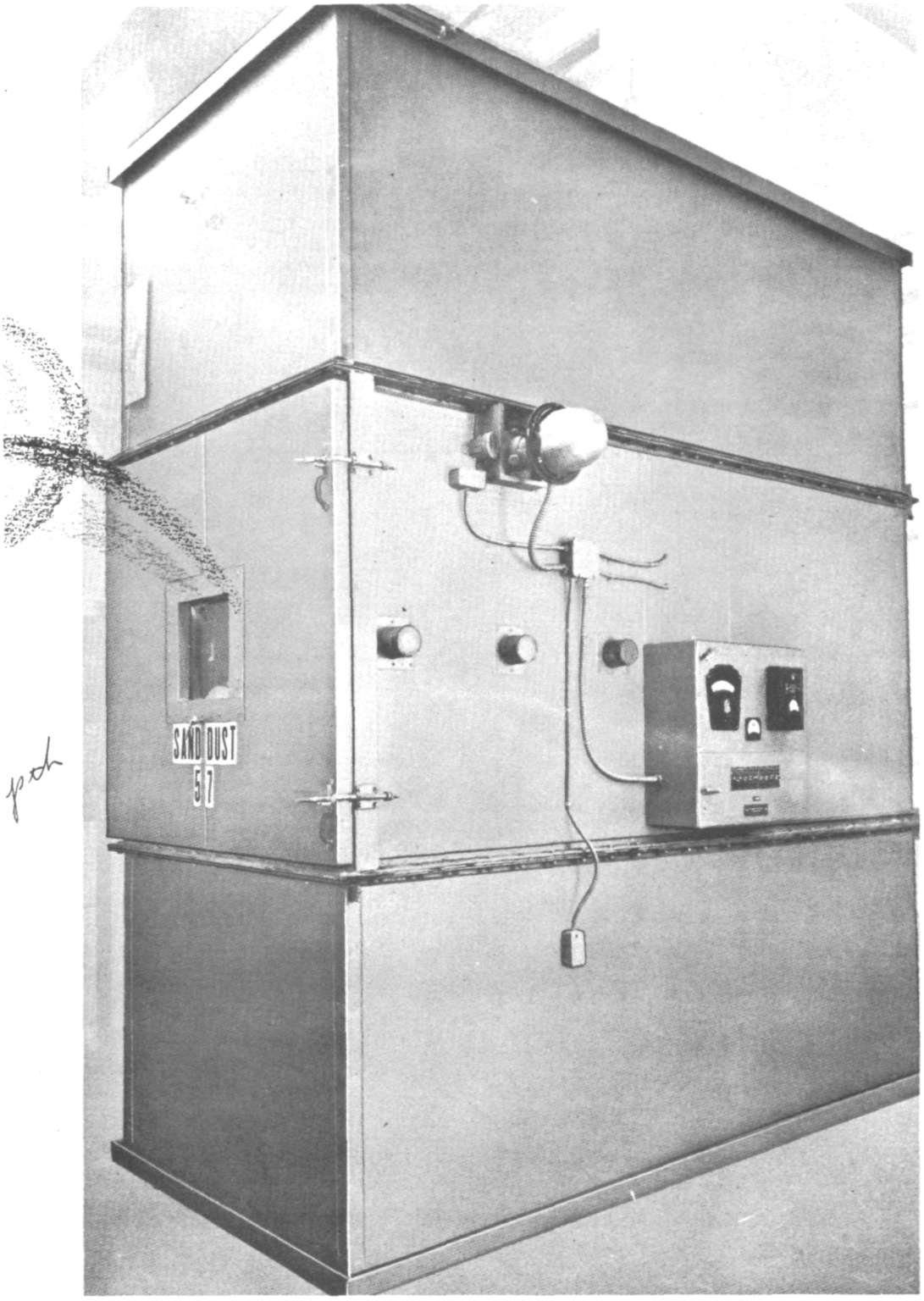

Figure B-136. Environmental Equipment 4 x 4 x 4 foot sand and dust chamber

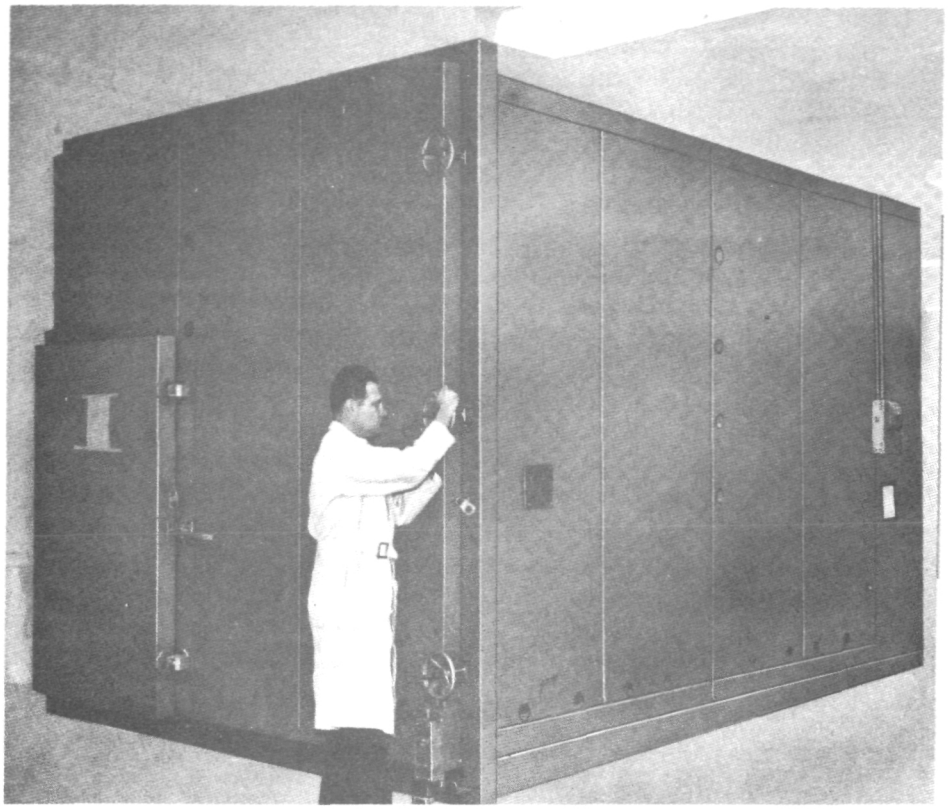

Figure B-137. International Radiant 9 x 9 x 12 foot fungus chamber

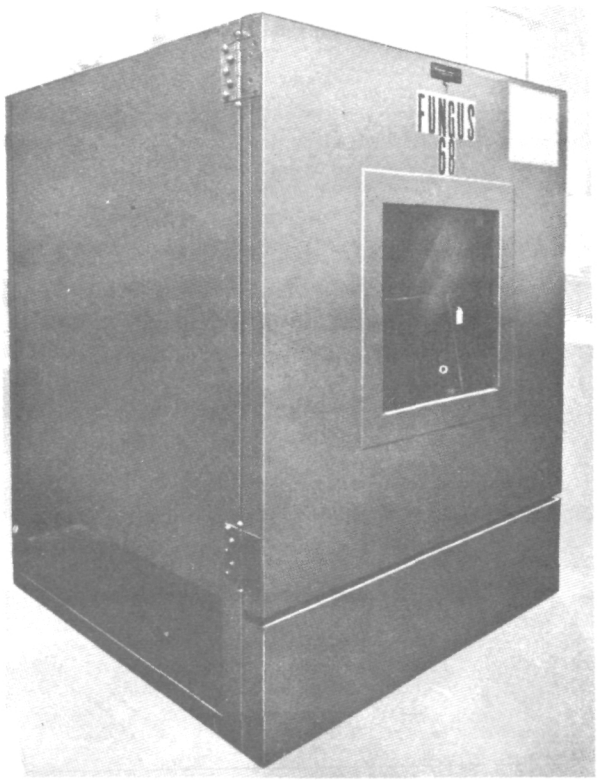

Figure B-138. Environmental Equipment 4 x 4 x 4 foot fungus chamber

1.3.8 Functional Test Equipment

The following functional test equipment is available at MSVD for functional testing of systems, subsystems and components.

1.3.8.1 AUTOMATIC TEST DIRECTOR AND ANALYZER

The Automatic Test Director and Analyzer is an advanced testing system that incorporates a digital computer-controller with an internally stored program having a capacity for 1000 test programs. Featured in this testing system is the G-E 312 computer, which possesses a fast arithmetic operation, an index register to facilitate programming, speed-up operations, and reduced storage requirements. Details are given in other sections of this document.

The use of this testing system offers greater testing flexibility, simplified testing, increased utilization in real-time testing, and improved testing and product reliability. The testing programs performed with this system provide a minimum of equipment "hook-up", an immediate use of as many as 1000 test programs automatically operated at rapid speeds, and a programmed problem solving capability.

The overall testing equipment includes four major functional sections: (1) Digital computer-controller, (2) stimuli, (3) switching circuitry, (4) measurement and printout equipment. The digital computer-controller includes a memory drum, input and output tape units, and arithmetic sections. The computer-controller permits advanced programming techniques and provides a sophisticated decision making capability. The overall mechanical configuration designed for economical use of space, consists of seven relay racks and one test console occupying an area of about 50 square feet. The input-output cabinets contain equipment such as a digital clock, an analog to digital converter, and low level amplifiers.

Summary of Capabilities for the Automatic Director and Analyzer

Capacity – Will accept 1000 complete test programs

Routines – Automatically apply stimuli, make measurements, control test sequence, perform evaluation, record and present data

Self-diagnostic routines – Calibration checks of computer and complete measuring system

Computations - Calculation of VSWR; solve equations and analyze faults that occur

Diagnostic routines – Troubleshooting for fault location when test measurement on system under test is out of tolerance

Warning operations – Loss of stimulus is indicated and computer will stop

The assembly of proven component parts such as the magnetic memory drum, the solid state matrix of parts, and the mercury wetted relays assures high testing accuracy and rapid testing cycles. In a Jones and Loughlin steel mill, for example, a comparable data logging system has operated for more than 4500 hours on a 24-hour day and a 7-day week without a failure. These assurances provide increased reliability in proof-tested systems equipment because the components and subsystems may be stressed in simulated environments and the strains may be rapidly and accurately measured and recorded.

The memory drum in the computer is a simple, reliable, rotating cylinder basically similar to turbine and generator rotors. It is completely enclosed in a dust tight housing. The bearings have a design life of 14 years for 90 percent confidence. The drum is warranted for five years.

The index registers have advantages which reduce storage requirements for the program, reduce programming cost, and increase the speed of the operating program. As an example, a program was coded on the G-E 312 with and without the use of the index register. It revealed the following advantages:

1. Reduced storage requirement for the program by 1/2.
2. Reduced the running time of the program by 1/3.
3. Reduced the programming time by a factor of 5.

4. A more reliable program is produced because the writing on the drum for a program modification is held to a minimum.

5. Simplifies programming and permits an optimum of assembled programs on the G-E 312.

1.3.8.2 INTEGRATED UNIVERSAL COMPONENT TESTER

Figure B-139 shows the Integrated Universal Component Tester used for component acceptance and manufacturing in-process testing.

The tester consists basically of six sections.

(1) Tape reader and decoder

(2) Programmable electrical stimuli

(3) Address modules and input connections

(4) Analysis selectors and instrumentation

(5) Comparator

(6) Output recording equipment

A typical component under test is connected to the tester using an adaptor cable. A pre-punched paper tape, containing the total test program is inserted in the tape reader. The operator then initiates the automatic portion of the test.

The programmed tape commands the tester to perform two types of tests. The first is a static test of the component. This sequence checks all test points of the component for proper resistance values. This test acts to protect the component in cases of faulty readings. The actual readings are compared to predetermined limits, and results are recorded by an electric typewriter, and also punched out on paper tape.

The second type of test is a dynamic exercise of the component. Here, operational power sources or stimuli are addressed to proper connections on the component.

The response to this stimuli is measured, compared, and recorded. In all cases, the machine may be programmed to stop or continue on receipt of an out-of-limit reading.

Because of the high degree of automaticity, more accurate measurements are made in a shorter period of time, interpretation of data is made by the tester rather than the operator, data is recorded on a data sheet and punched on tape, thus eliminating transcription error. Another feature of the tester is the extremely high degree of repeatability in the performance of the test. Thus, changes in output due to various environments become strictly a function of the component rather than the test equipment.

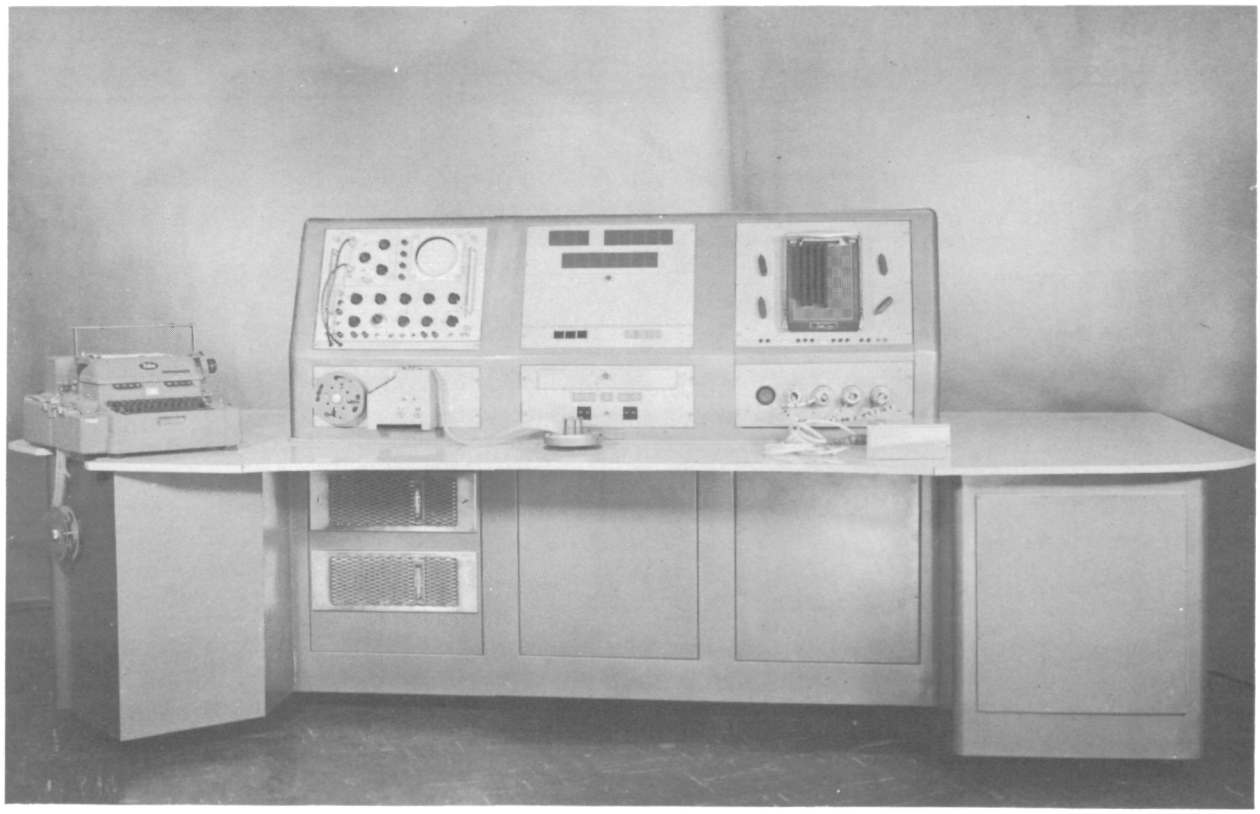

Figure B-139. Universal component tester

1.3.8.3 AIR BEARING DYNAMIC SIMULATOR

The Air Bearing Dynamic Simulator shown in Figure B-140 has three degrees of freedom. It is designed to accurately evaluate attitude control system and subsystem performance. Each complete system and subsystem evaluated on the three-axis simulator has a platform which closely approximates the actual vehicle size, shape and mass moment of inertia about each of the three rotational axis. This platform provides a stable base for the interconnecting components or subsystems to be evaluated. Following subsystem assembly and interconnection on the caged platform table, compatibility checks and power consumption measurement are made, and instrumentation calibration performed using external power. When these tests are deemed satisfactory, external power is disconnected and the platform table is released for the following operational tests:

1. Frequency response of the system.
2. Sensor and amplifier gradients.
3. Cross coupling.
4. System response to a position plus velocity input.
5. Compatibility of components to perform operations of system.
6. Inertial and reaction impulse characteristics.
7. Energy (electrical and pneumatic) consumption.
8. Sensor sensitivity and noise levels.
9. Simulated flight performance.

1.3.8.4 DYNAMIC STABILIZATION SIMULATOR

MSVD's stabilization simulator is capable of supporting 8000 pounds.

This simulator provides a test fixture for the evaluation and refinement of components interconnected to perform a specific subsystem function in the operation of space vehicles. It is flexible and accurate to permit rapid preliminary testing

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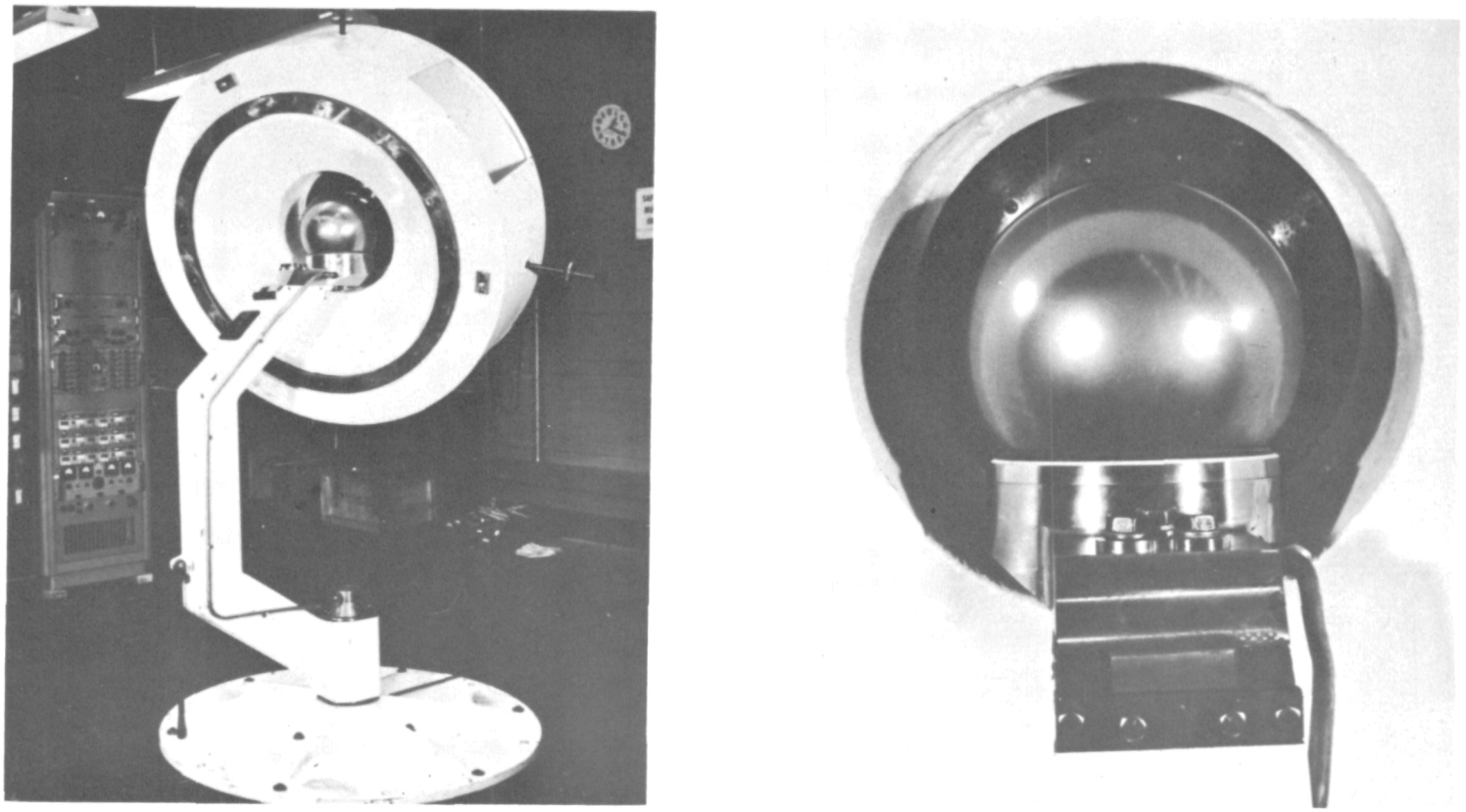

Figure B-140. Air bearing dynamic simulator

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of subsystems so conclusions can be effectively utilized in the final definition of the subsystem. See Figure B-141.

Subsystem testing will consist of work in the following areas:

(1) Infrared sensing

(2) Star and sun tracker sensing

(3) Magnetic field sensing

(4) Inertial forces sensing

(5) Rate and attitude sensing

To permit evaluation of the interrelationship of the energy from these several sources, the stable platform will provide for interconnecting components such as amplifiers, servo-mechanisms, motors, generators, power supplies, and pneumatic or other impulse subsystems.

Normally, in utilizing this equipment, MSVD does not employ interconnecting wiring in order to reduce friction to a minimum. Information during testing is obtained by utilizing the airborne telemetry subsystem on the satellite undergoing test and a ground station for handling the transmitted data. Test areas especially adaptable to the use of this simulator are; cross-coupling, simulated flight, inertial orientation, orbital flight, and tests requiring dark periods and "high-noon" conditions. Mutually independent earth and sun motions allow for programmed orbits and condensed tests.

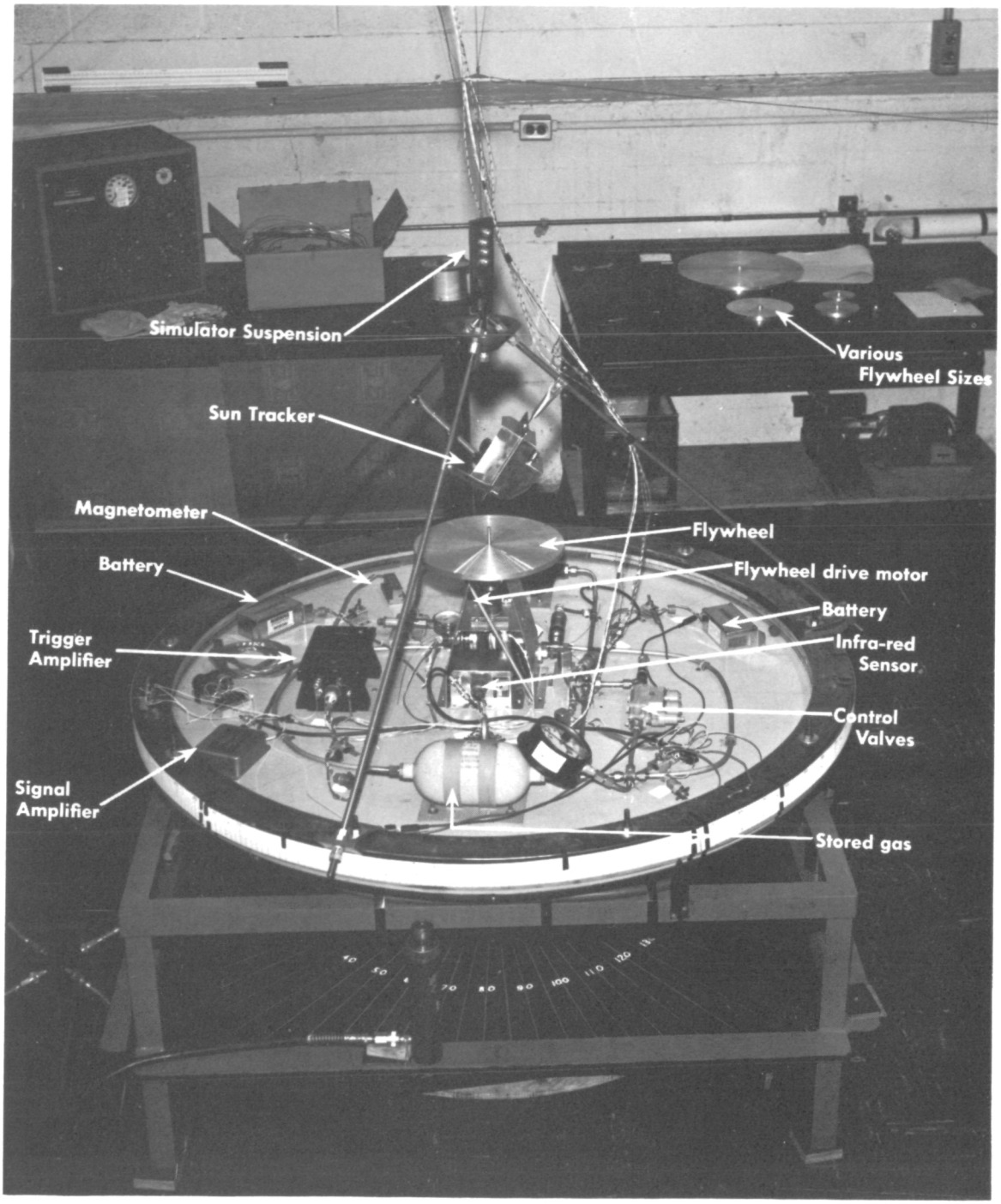

Figure B-141. Dynamic stabilization simulator

1.3.8.5 SIDERIAL TABLE

Figure B-142 shows a siderial table with its test console which is used for gyro testing and star tracker studies and testing.

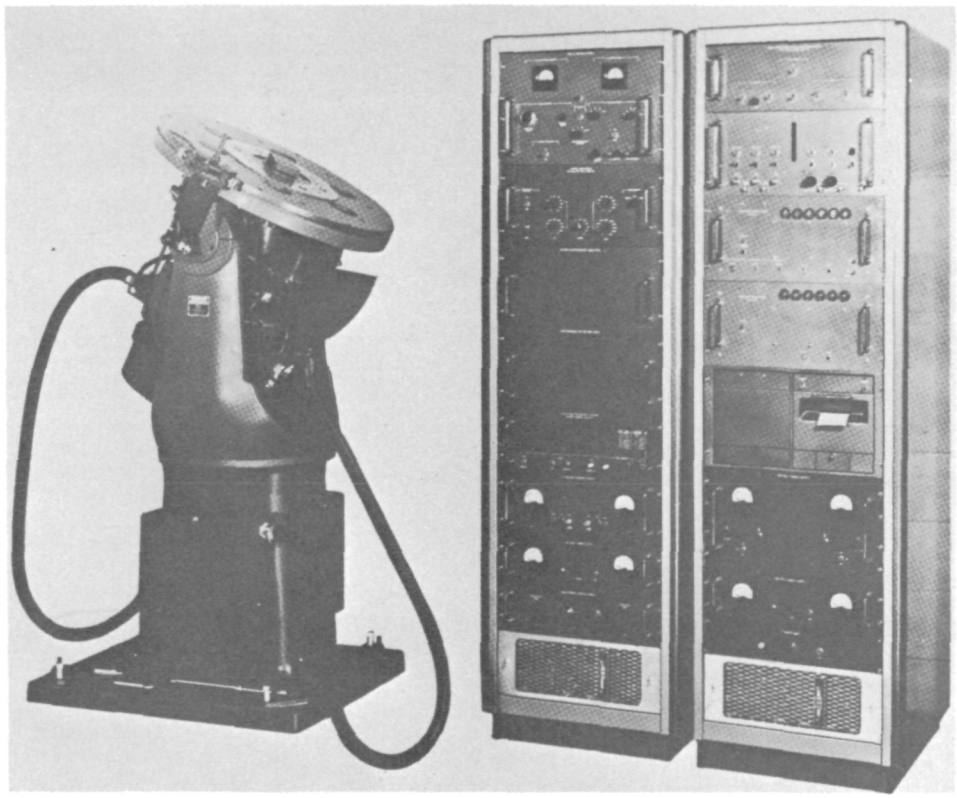

Figure B-142. Siderial table and test console

1.3.8.6 OUTDOOR ANTENNA RANGE

Figure B-143 shows the outdoor antenna range, with the capability to make impedance, pattern, gain, and field strength measurements on all types of space vehicle antennas.

Figure B-143. Outdoor antenna range

A new $400,000 antenna range will be available at Valley Forge. This will include a laboratory for antenna and waveguide studies; two antenna pattern ranges with rail-mounted model towers; and a radar cross-section range where the test model will be suspended 50 feet above the ground on a nylon rope strung between two towers. Scale models up to 350 pounds may be mounted on the model towers while the nylon rope of the radar test range will support up to 2000 pounds. More than $125,000 worth of instrumentation will be installed to provide new dimensions of flexibility and accuracy.

1.3.8.7 RECORDING UNIVERSAL SPECTROPHOTOMETER

Figure B-144 shows the recording Perkin-Elmer Model 205 Universal Spectrophotometer, a unique double beam spectrophotometer having the capability of operation

in the ultraviolet, visible, near infrared, and far infrared (to 35 microns) regions of the spectrum. The instrument is designed to compute and record automatically and continuously transmittance, reflectance and emissivity of materials.

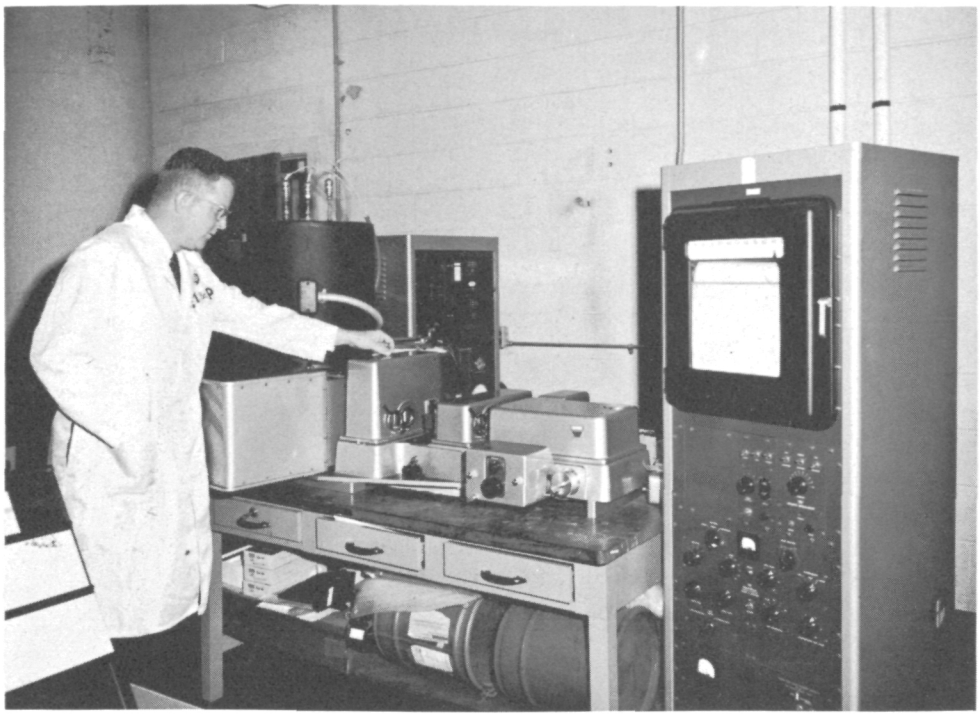

Figure B-144. Recording universal spectrophotometer

1.3.8.8 RADIO NOISE ROOM

Figure B-145 shows the 10 x 8 x 27 foot Radio Noise Room used for development testing. The room meets the performance requirements of government specifications MIL-E-4957A, 16E4, MIL-I-6181, JAN-I-225 and MIL-I-16910.

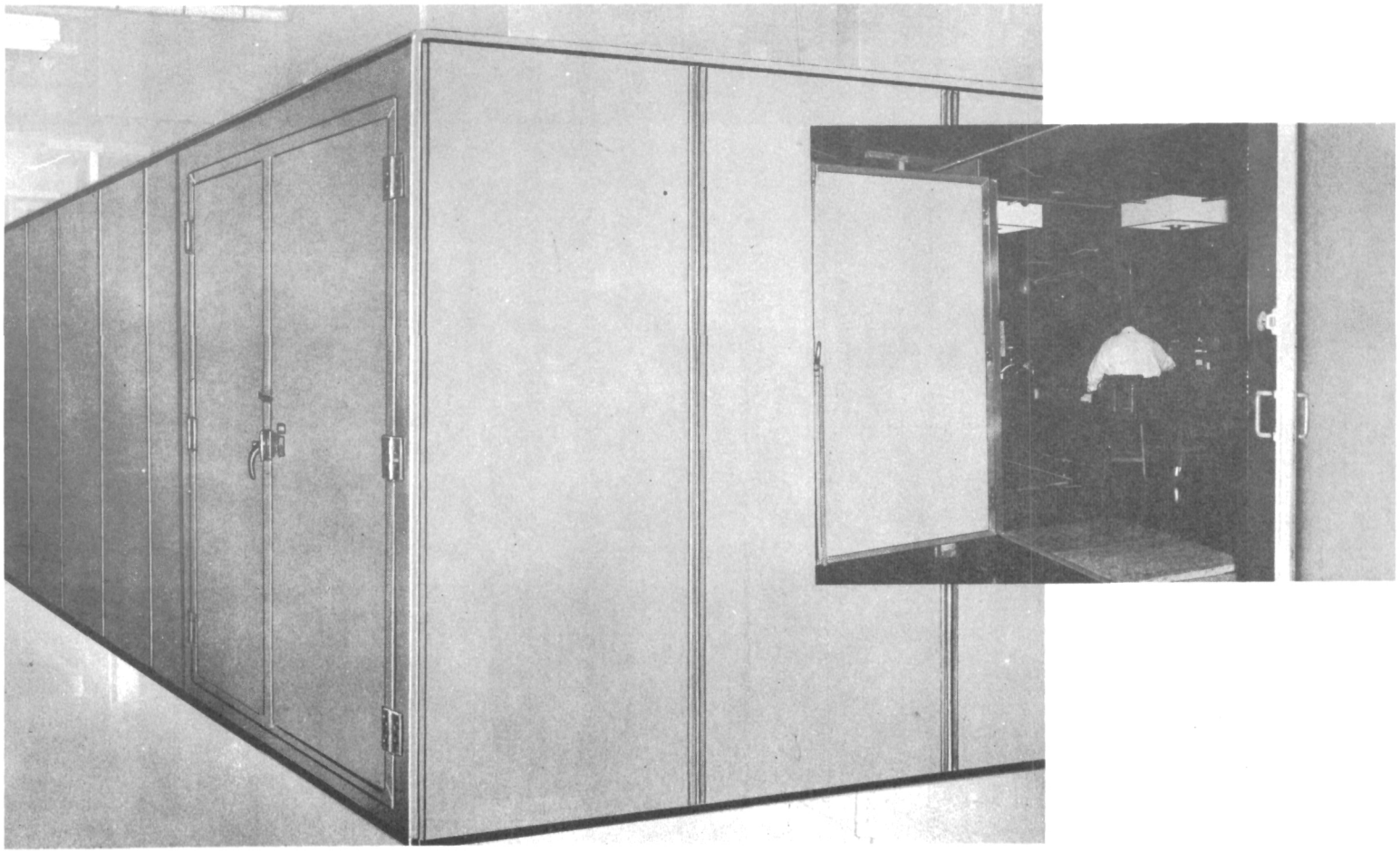

Figure B-145. Radio noise Room

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1.3.9 Acoustic Test Facility

The acoustic test facility permits investigation of missile and space vehicle systems or components when subjected to high intensity noise fields simulating the actual flight acoustic environmental conditions developed by rocket motors, jet engines and the aero-dynamic characteristics of the turbulent boundary layer.

The present facility consists of the following:

1. Reverberant Chambers - random noise air chopper as source.
   (a) 120 cu ft chamber, 160 db over-all sound pressure level continuously, 163 db (estimated) for approximately 50 seconds. (See Figure B-146.)
   (b) 3000 cu ft chamber, 155 db over-all sound pressure level continuously, 158 db over-all sound pressure level approximately 50 seconds.
2. Progressive Wave Tubes - 29 in. x 29 in. 160 db over-all sound pressure level — random and sinusoidal noise sources.
3. Anechoic Chamber - 44 in. x 44 in. x 44 in. free field with a low frequency cut off of 150 cps, with an over-all noise reduction coefficient of 0.95.
4. Sound Sources
   (a) Electro-dynamic loudspeakers
      1. Atlec lansing 15 in.woofers, 75 watts
      2. Atlec lansing 6 in. midrange drivers, 125 watts
      3. University B12 PAHF loudspeaker system, 600 watts
   (b) Mechanical systems
      1. Wide band random noise air chopper providing 170 db over-all sound power level for a noise spectrum from 40 cps to 10KC.

2. Sinusoidal siren is under development utilizing the present wide band chopper by replacing one of the four random rotors with a sine rotor and special orifice designed by Structures Laboratory.

5. Instrumentation - Instrumentation system to record and analyze the acoustic noise fields.

   (a) Condenser and crystal type microphones, Bruel & Kjaer, Atlec Lansing and Massa.

   (b) Bruel & Kjaer 1/3 octave and octave band audio frequency spectrometer.

   (c) Bruel & Kjaer level recorder.

   (d) Ampex AM/FM four channel magnetic tape recorder and a fourteen channel CEC FM magnetic tape recorder.

6. Air Supply consisting of an Ingersol Rand XLE air compressor and receivers providing 600 CFM continuously and 6000 CFM for 50 seconds utilizing blow down techniques.

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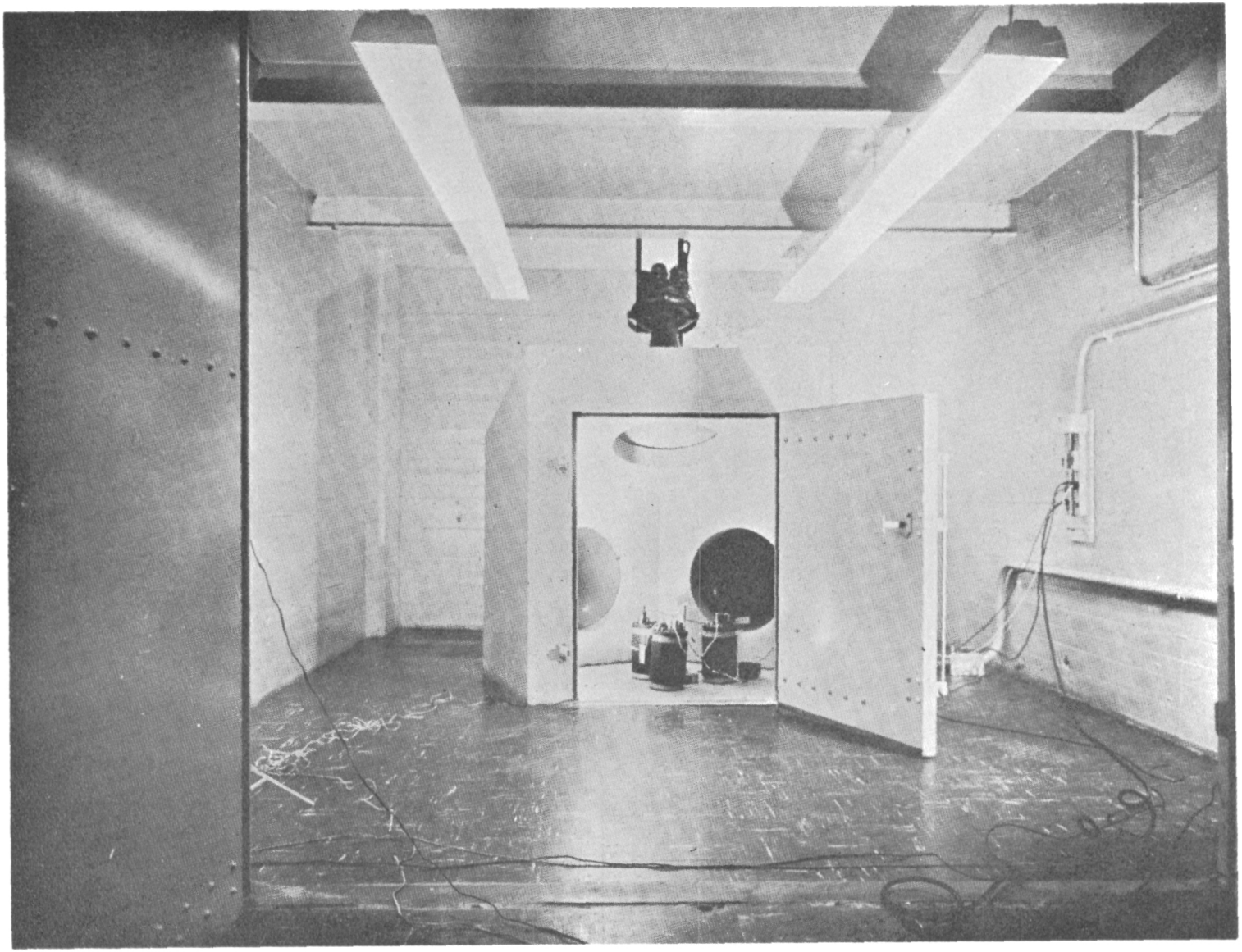

Figure B-146. Reverberant chamber, 120 cu ft

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1.3.10 Standards Laboratory

Measurement accuracy is a recognized and controlled need. Complete facilities as well as a thoroughly trained and specialized force is located at the Philadelphia Plant. The MSVD Primary Standards Laboratory is a temperature and humidity controlled, dust free area containing primary standard systems to permit all Department measurements to be traceable to one area. This area, in turn, is traceable to the National Bureau of Standards Certifications. It is continually modified and supplemented to meet the demands of commerical measurements in accordance with Government Specifications.

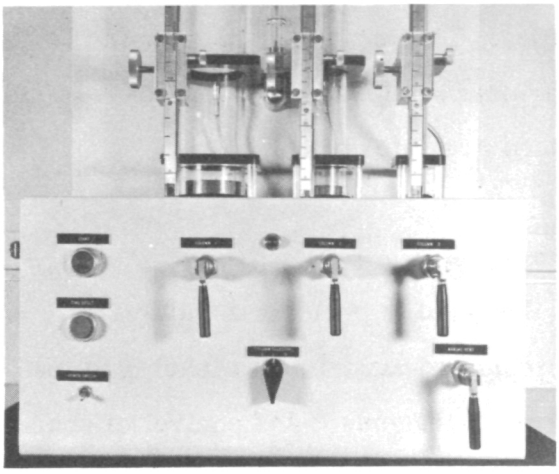
The capabilities encompass standards of measurement in all d-c and a-c applications, temperature, pressure, vacuum, Radio Frequency, Time Frequency, Meteorology, Weights and Vibration with capabilities for 40 parameters. Figure B-147 shows some of the precision equipment in the Standards Laboratory.

1.3.11 Satellite Tracking Facility

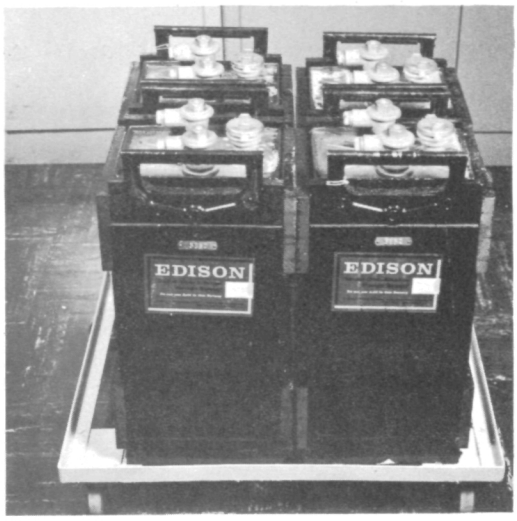
A Photo Electrical Observatory was established with financial support from the General Electric Company MSVD, Ordnance Department, Heavy Military, Light Military, Communications Products, Power Tube Department, and General Engineering Laboratory late in 1959. It is located in the same building as the General Engineering Laboratory Radio Space Tracking Facility so as to make the problem of co-operation and co-ordination a simple one. In this way co-operative, optical, and radio tracking is feasible under a number of conditions.

The combination of optics and radio tracking is quite unique. There are many defense sponsored tracking stations in the country, but few operating in this combined manner, and we believe the General Electric facility is the only privately owned one in the country.

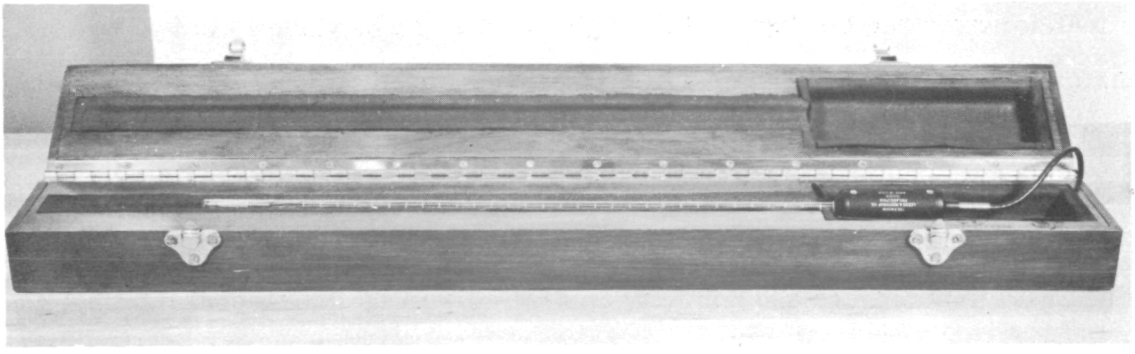
The present capabilities of this station include the tracking of 9th magnitude or better satellites with the image orthicon, the limit being set primarily by the rate



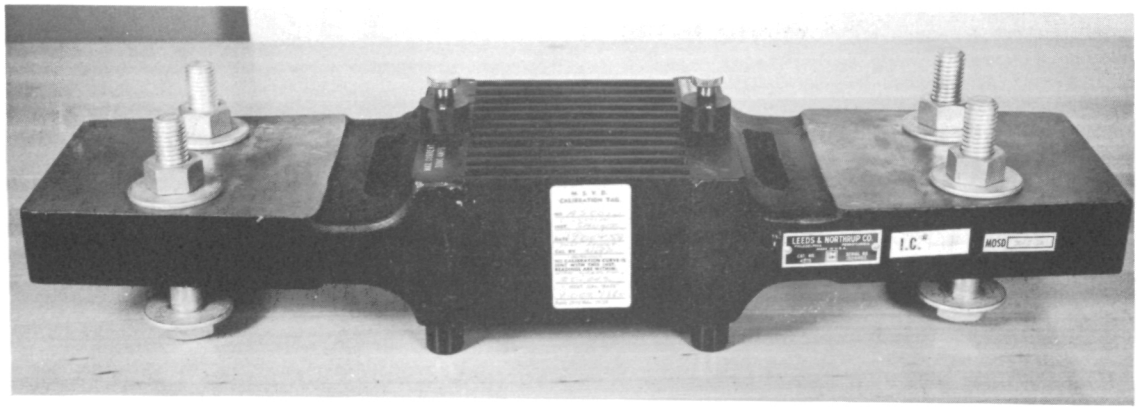
Flow Calibrator



Edison Storage Cell



Platinum Resistance Bulb Thermometer



3000-Amp Current Shunt

Figure B-147. Some representative equipment of the standards laboratory

the object is moving and the accuracy of the data. With slow moving objects and fields, the present limit is about 16 magnitudes. The image orthicon chain is capable of integration out to 20 seconds. Variable scan rate and variable resolution data are recorded photographically and reduced at a later time.

1.3.12 Biosciences Development Laboratory

The Biosciences Development Laboratory is designed to perform a wide variety of psychological, physiological, and biological tests and experiments leading to the development of practical systems for the human management and control of space vehicles. A special laboratory area has been fabricated for the study of manual control, piloting, and management of space vehicles. The laboratory includes a 100-square-foot simulator area and a 350-square-foot observation-computer-programmer area. This facility is so arranged that the performance of the subject in the simulator area can be observed through one-way glass windows in two walls. The simulator room itself has been designed to provide sound attenuation of at least 30 db at 125 cycles and its six-inch-thick concrete walls have been isolated from the floor and ceiling by cork. The net effect is, essentially, acoustic isolation of subjects in the simulator room from extraneous noise sources. The simulator area is provided with temperature and humidity control as well as fluorescent lighting, the intensity of which is continuously variable from zero to 65 foot-candles, controlled from the observation area. A unique panel board between the simulator area and the observation area provides for the interconnection of circuits from inside to outside the simulator area. (See Figure B-148.)

The observation-computer-programmer area has its own analog computer facility (a 60-amplifier analog computer is permanently installed in this area). In addition, the laboratory is located directly beneath the Department's main analog computer facility, and hard-wire connections to this facility have been installed.

A partial equipment list for this human factors laboratory includes the analog computers already mentioned, associated equipment such as function generators,

function multiplers, etc., and a specially procured low-drift oscilloscope which has been modified so that it can operate either a four-independent-gun display or a two-gun x-y mode. Provisions have been made so that "off-the-shelf" equipment can be added to it to produce a four-gun x-y display. This specially designed oscilloscope, with its inherently greater flexibility and versatility will enhance the capabilities of the laboratory to investigate the problems of display synthesis and integration without the customary necessity of design and fabrication of special electronic circuitry.

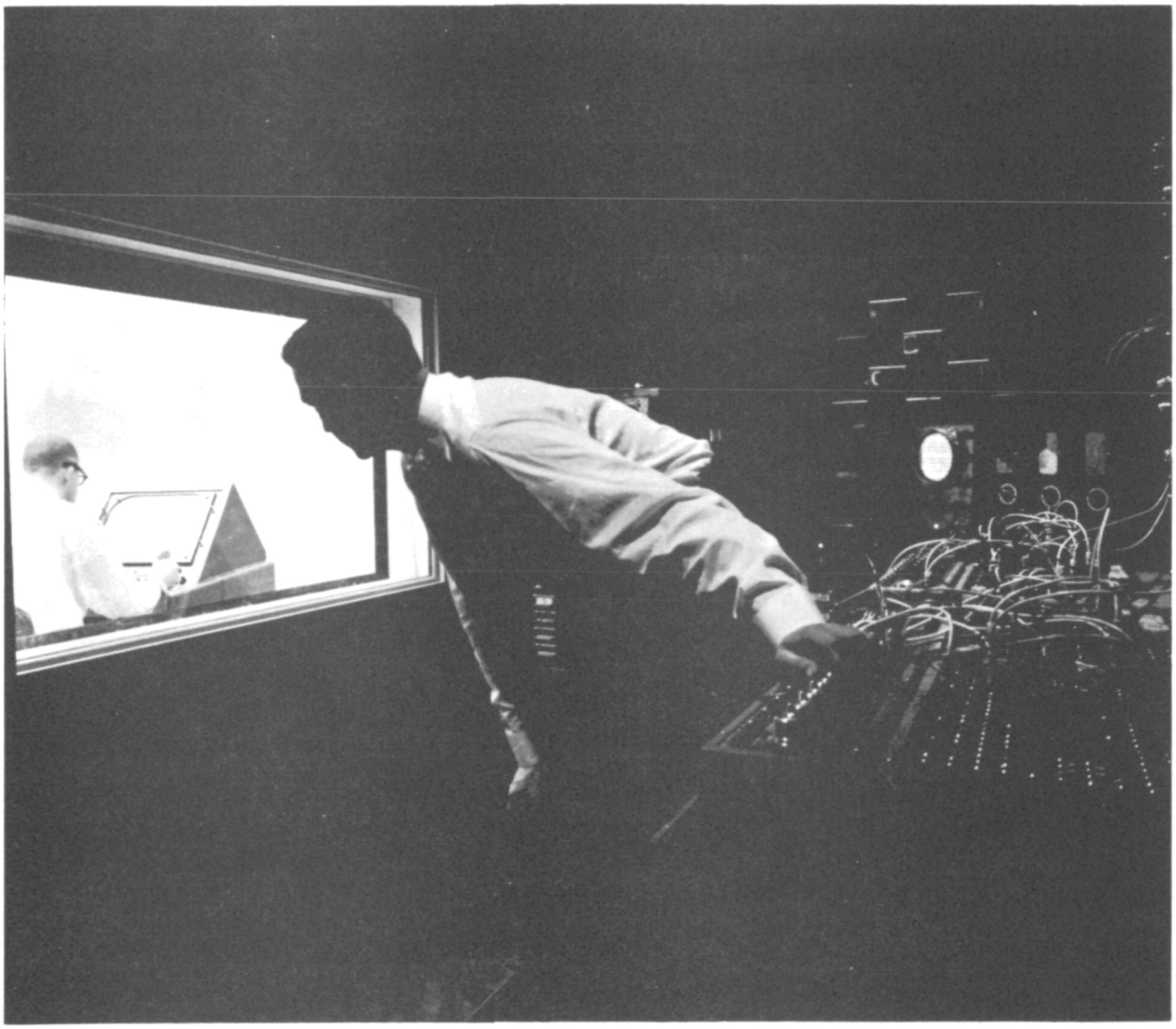


Figure B-148. Biosciences development laboratory — simulator area

The Biosciences Development Laboratory is also designed to perform a wide variety of biological, physiological, and psychological tests and experiments leading to the development of practical life-support systems for space vehicles. This modern MSVD facility is especially equipped for the testing of environmental control systems and equipment, for the study of gaseous environments as maintained by photosynthetic and physical means, and for the study of toxic products that may be generated by animals, plants, and hardware. The versatility of the Biosciences Development Laboratory will enable it to play an important part in future MSVD programs involving the development of practical ecological systems and the creation of inhabitable environments for human beings in space. (See Figures B-149 and B-150.)

1.3.13 Structures Laboratory

The MSVD Structures Laboratory is used to study the performance characteristics of structures and components under conditions of static and dynamic loading, thermal shock, acoustic fatigue, and similar physical environments.

Available in the laboratory are tensile test equipment (Figure B-151), a 120,000 pound temperature tension and compression test machine (Figure B-152), a 150,000 pound automatic cycling tension-compression machine, and a 12,000 pound creep machine. Other shock, vibration, noise and acceleration machines described earlier in this section are also part of the laboratory.

Figure B-153 lists static, dynamic and acoustic instrumentation used with the above equipment.

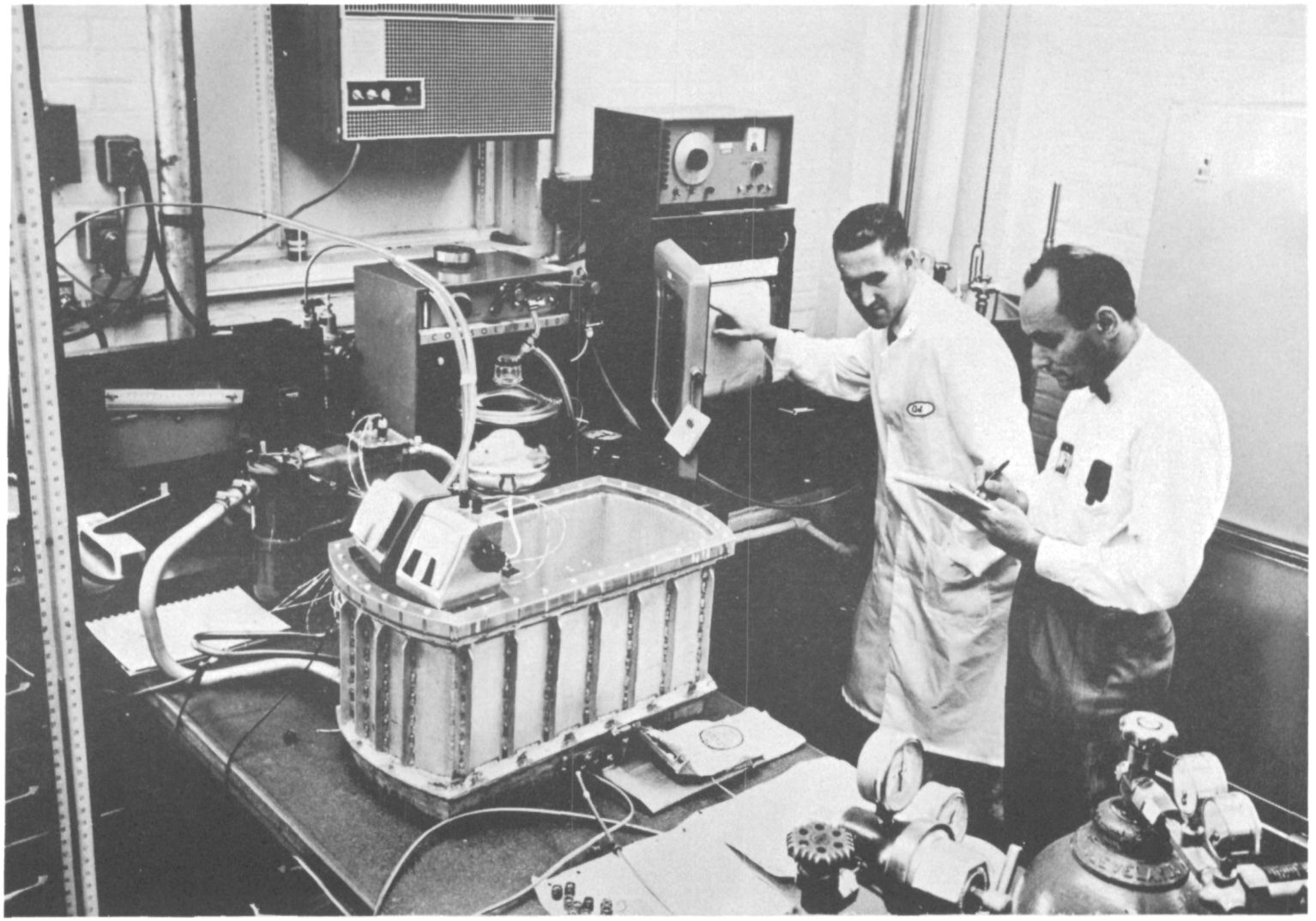


Figure B-149. Biosciences development laboratory — biological experiment on animal subject

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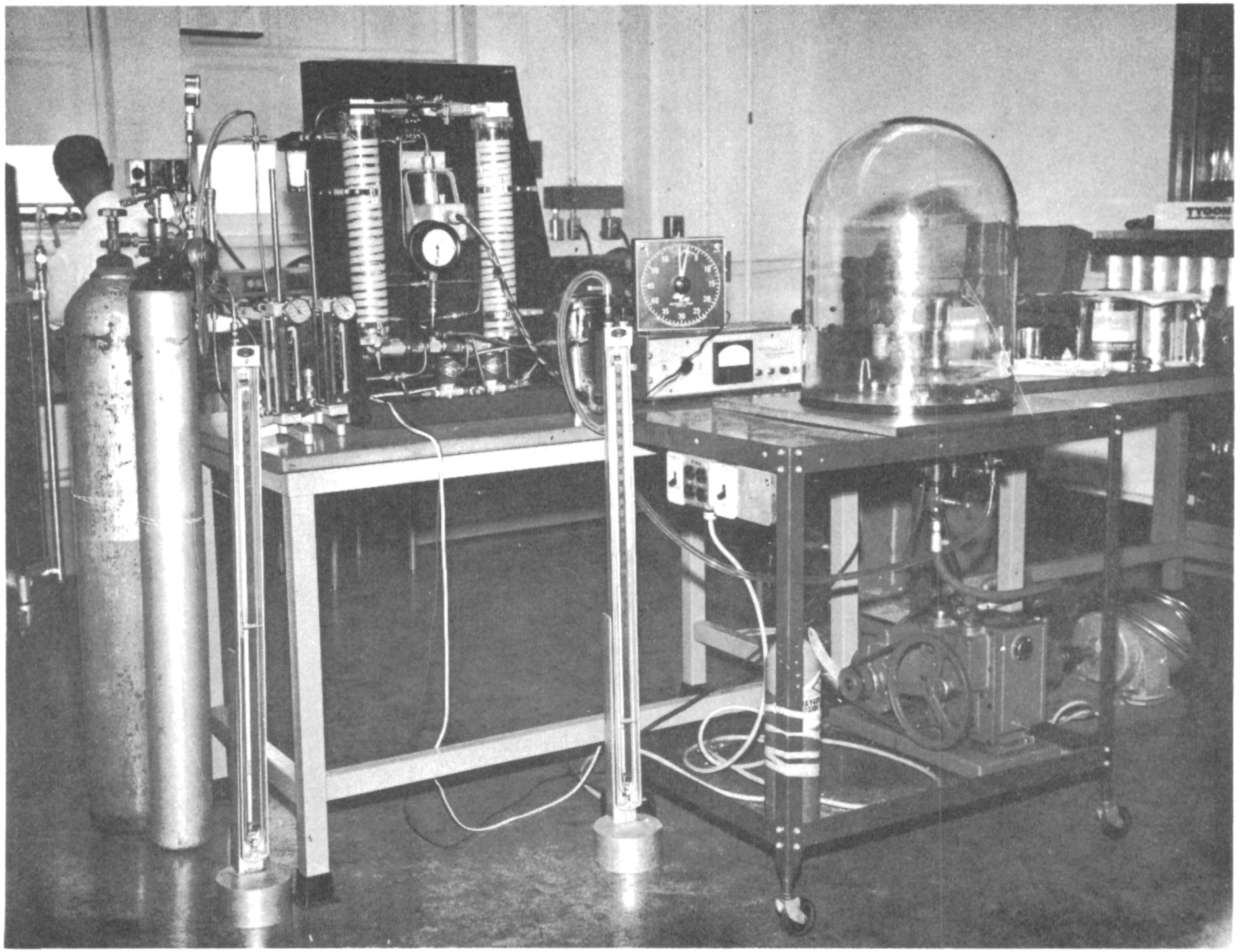

Figure B-150. Experimental test set-up, cycling molecular sieve approach

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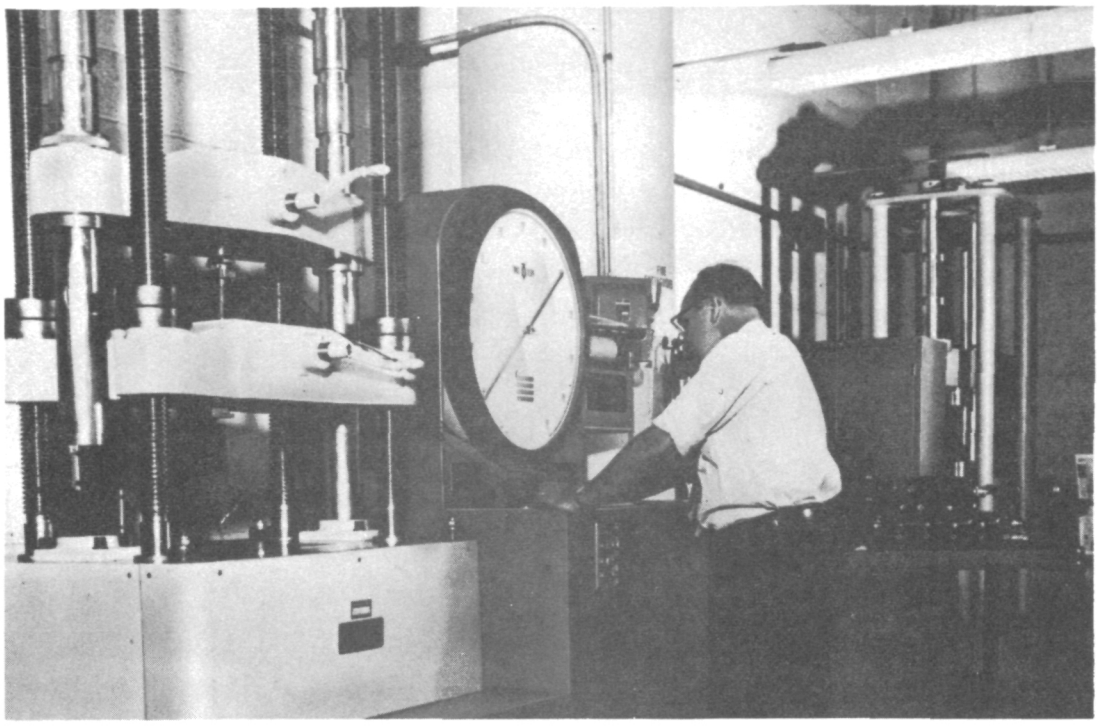

Figure B-151. Tensile test equipment

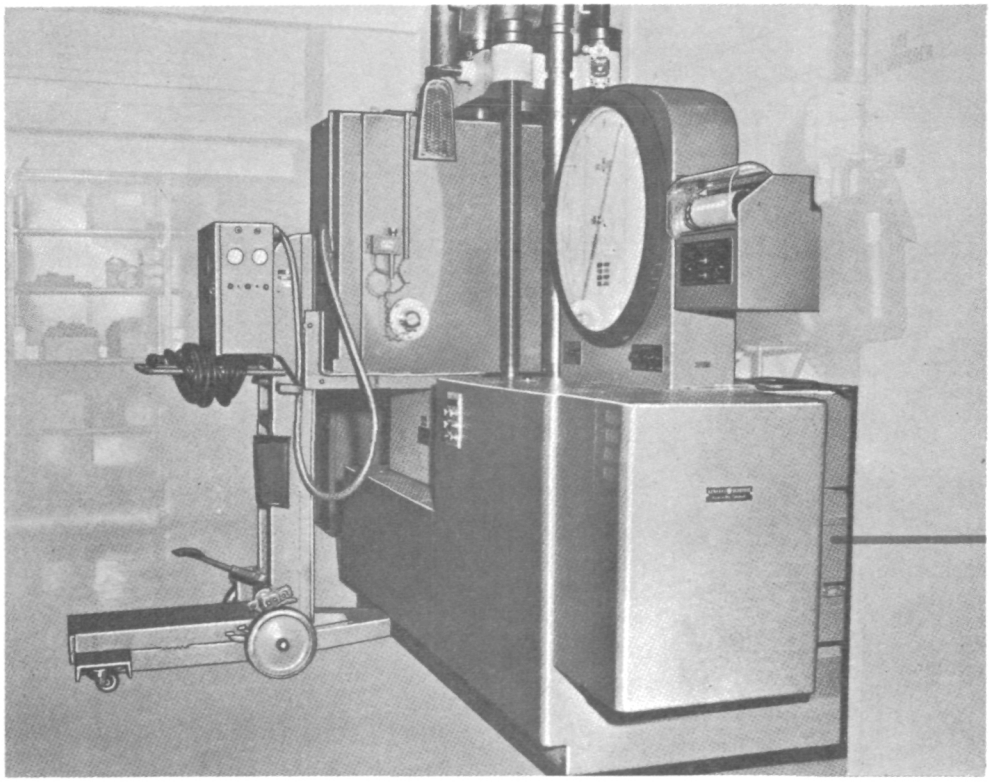

Figure B-152. Temperature tension compression test machines

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STATIC TEST INSTRUMENTATION	DATA CHANNEL CAPACITY	REMARKS
Multiple-Channel Data Logging and Plotting Systems are available in the laboratory for recording strain, force, deflection, pressure, position, temperature and other physical and electrical variables. Systems can be provided to perform control functions. Load, pressure and temperature standards are available for the calibration sensors used in static testing.	(1) 200 Channel Semi-Automatic Recording System	Punched Tape and Flexowriter Tabulations (30 Data Points/Min).
	(1) 48 Channel Data Plotting System	Automatic Plotting of incremental load vs. strain.
	(1) 36 Channel Recording Systems and three (18) Channel Recording Systems	Recording Oscillographs and Signal Conditioning Equipment-Frequency Response D.C. to 600 cps.
	(3) 24 Channel Strip Chart Temperature Recorders	Sequential Plotting of Temperature.
	10 Channels Direct Writing Recorders	Ink and Electric Writing-Frequency Response D.C. to 60 cps.
DYNAMIC TEST INSTRUMENTATION		
Multiple-Channel and Single-Channel Instrumentation are available for recording and measurement of acceleration, velocity, displacement, strain and other rapidly occurring variables. Analysis of complex waveforms can be performed with magnetic tape loop playback in conjunction with a harmonic wave analyzer. Electro Dynamic, Piezo-Electric Exciter Systems, and resonant beams are available for the calibration of vibration sensing instruments.	(2) 14 Channel Magnetic Tape Record and Reproduce Systems	Wide Band F.M. - Frequency Response D.C. to 10,000 cps.
	(2) 18 Channel Recording Systems	Recording Oscillographs and Signal Conditioning Equipment-Frequency Response 5 cps. to 5,000 cps.
	(1) 16 Channel Recording System	Multi-Channel Cathode Ray Oscillograph-Frequency Response D.C. to 50,000 cps.

Figure B-153. Structures laboratory instrumentation facilities

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DYNAMIC TEST INSTRUMENTATION (Cont'd)	DATA CHANNEL CAPACITY	REMARKS
Calibrations can be performed at acceleration levels to 100 g in the frequency range of 5 cps. to 10,000 cps. A Ballistic Pendulum is also available for shock evaluation of transducers to acceleration levels of 1000 g at pulse durations of .001 seconds.	(3) Persistent Screen Oscilloscopes	Continuous storage of data display- permanent records obtained by Land Cameras.
	(1) Wave Analyzer System	Harmonic analysis of complex wave forms in terms of amplitude and forcing frequency or power spectral density plots as a function frequency. Extended system provides automatic plotting of attenuation or amplification factors.
ACOUSTIC INSTRUMENTATION		
Mechanical Vibration and Strain induced by high level sound fields can be recorded and analyzed in the laboratory. Sound pressure levels are measured, frequency analyzed and recorded simultaneously. Calibration facilities are available providing electrostatic frequency response calibration of condensor microphones over a frequency range of 20 cps. to 70,000 cps. Absolute sensitivity calibrations are performed applying reciprocity techniques.	(1) 4 Channel Magnetic Tape Record and Reproduce System	Wide Band F.M. - Frequency Response D.C. to 10,000 cps. A.M. - Frequency response 100 cps. to 100,000 cps.
	(2) Level Recorder and 1/3 Octave Spectrum Analyzer Systems	True R.Ms, Average and Peak indicating level in voltage or db. - frequency analysis 16 cps. to 30,000 cps.
	(8) Condensor Microphone Cathode Follower Systems	Frequency Response 20 cps. to 20,000 cps. Dynamic Range 15 db. to 165 db.
	(2) High Frequency Microphones- Cathode Follower System.	Frequency Response 20 cps. to 40,000 cps. Dynamic Range 32 db. to 160 db.

Figure B-153. (Cont.)

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1.3.14 Flight Test and Field Facilities

MSVD has test and field facilities in place and functioning at the Atlantic Missile Range (AMR) and the Pacific Missile Range (PMR) consisting of flight test and support equipment and experienced personnel. Test engineers act as pay load vehicle test conductors during missile firings and are responsible for payload vehicle check-out, system test, modification, retrofit, and launch operations. They receive flight test data and transmit it to the data processing center at MSVD, Philadelphia for processing. Some of there facilities are shown in Figures B-154 through B-157.

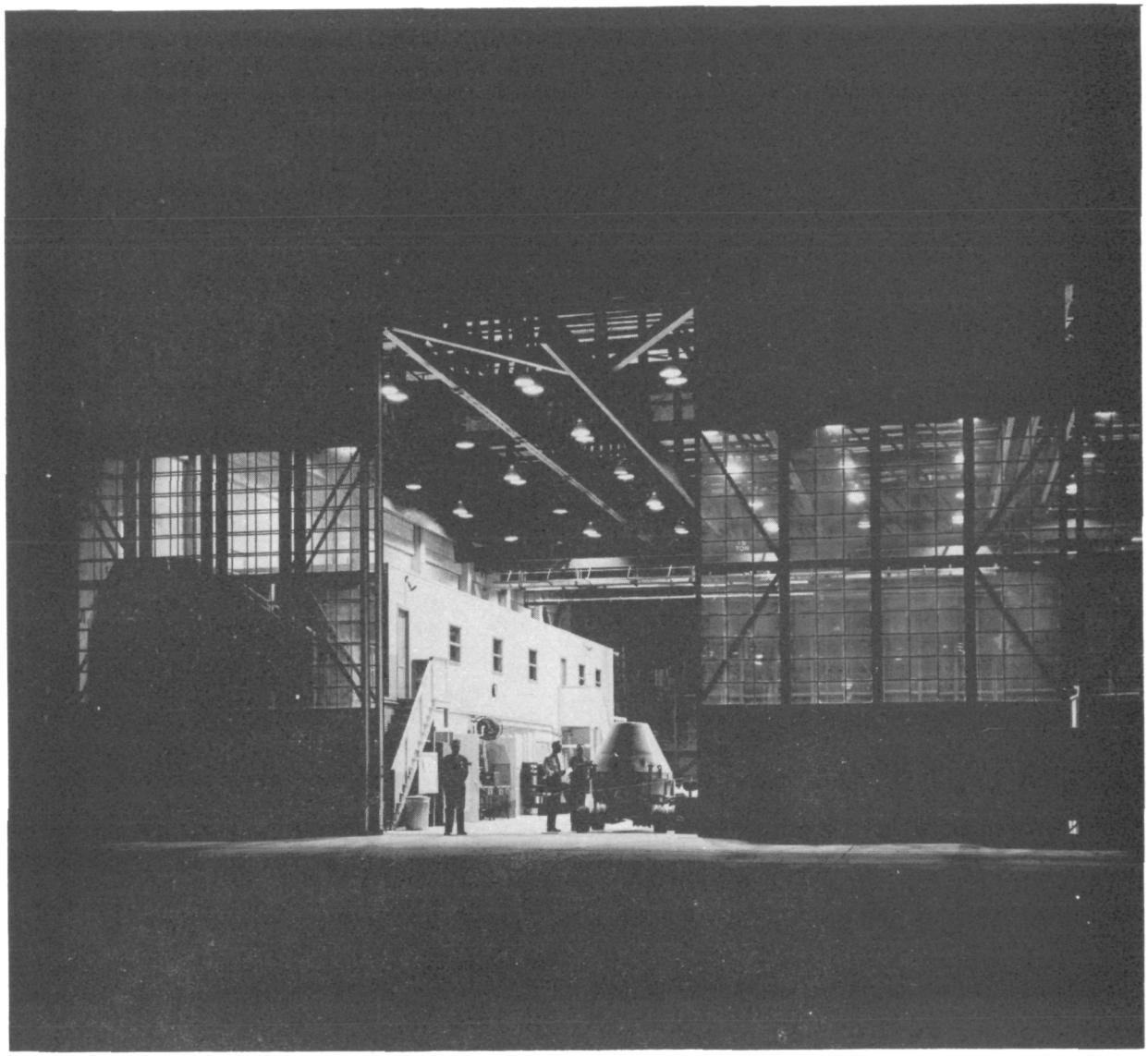

Figure B-154. MSVD flight-test hanger at AMR

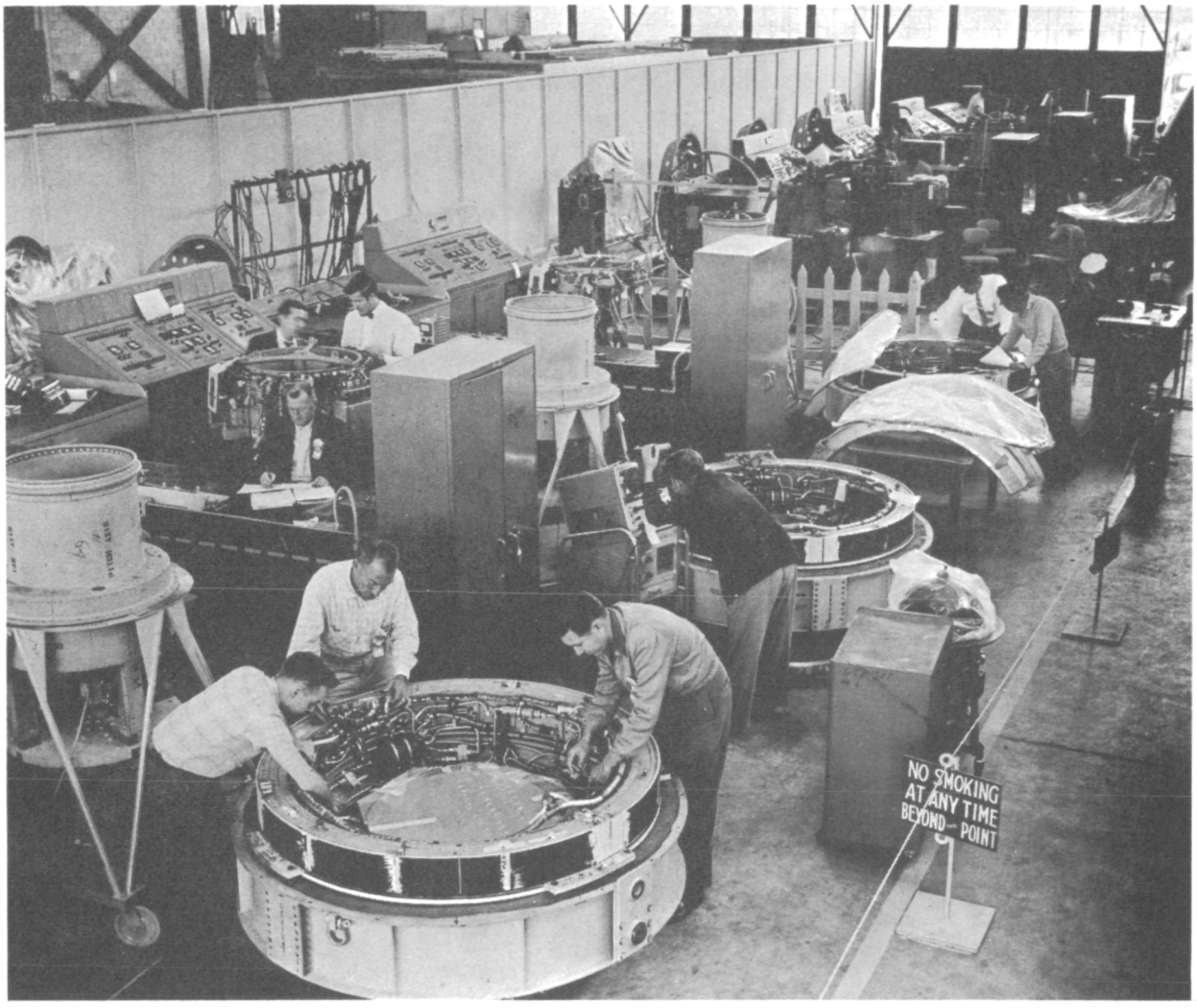

Figure B-155. Pre-flight checkout of Mark 2 re-entry vehicles in MSVD flight test facilities

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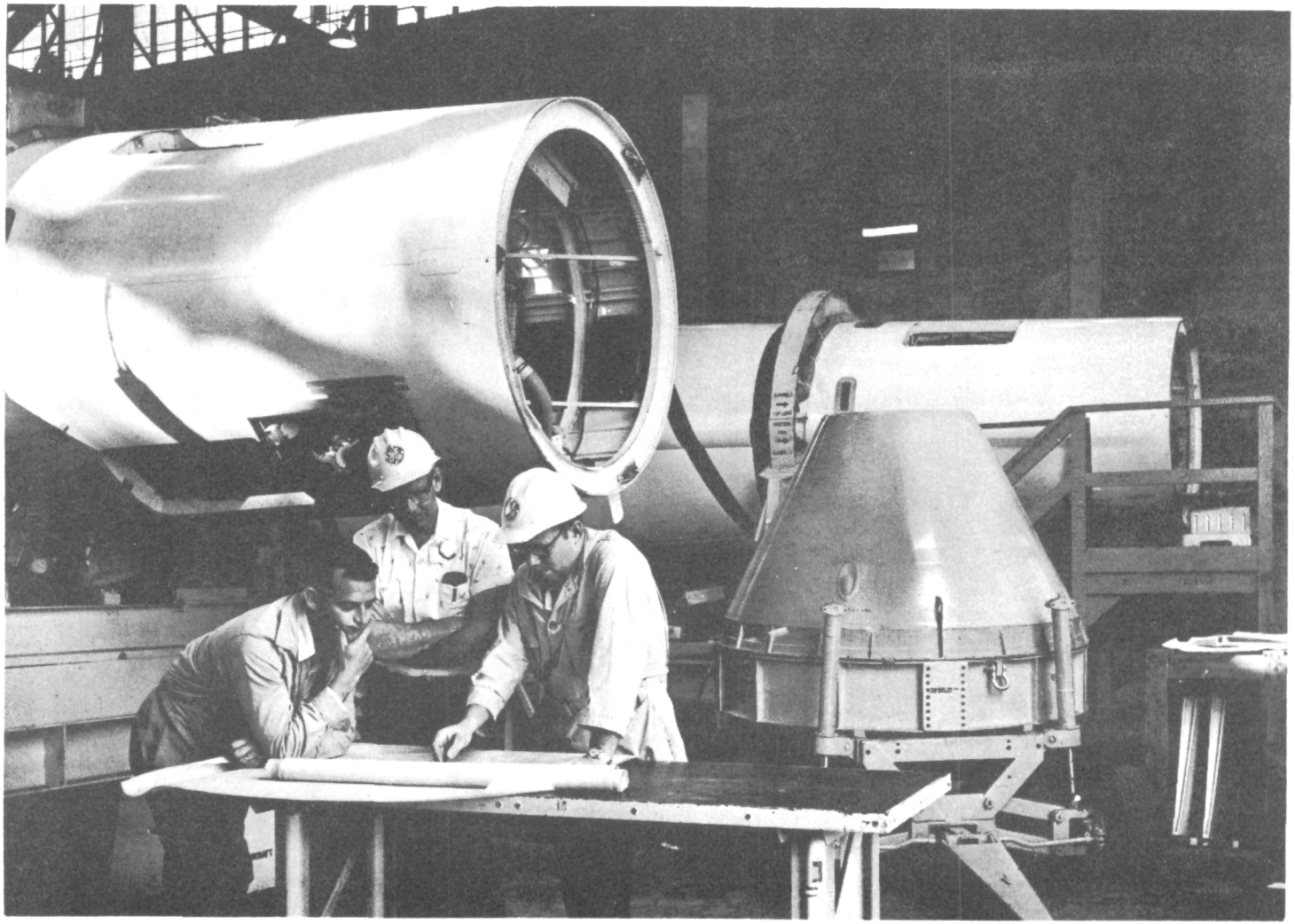

Figure B-156. MSVD flight test hangar at AMR

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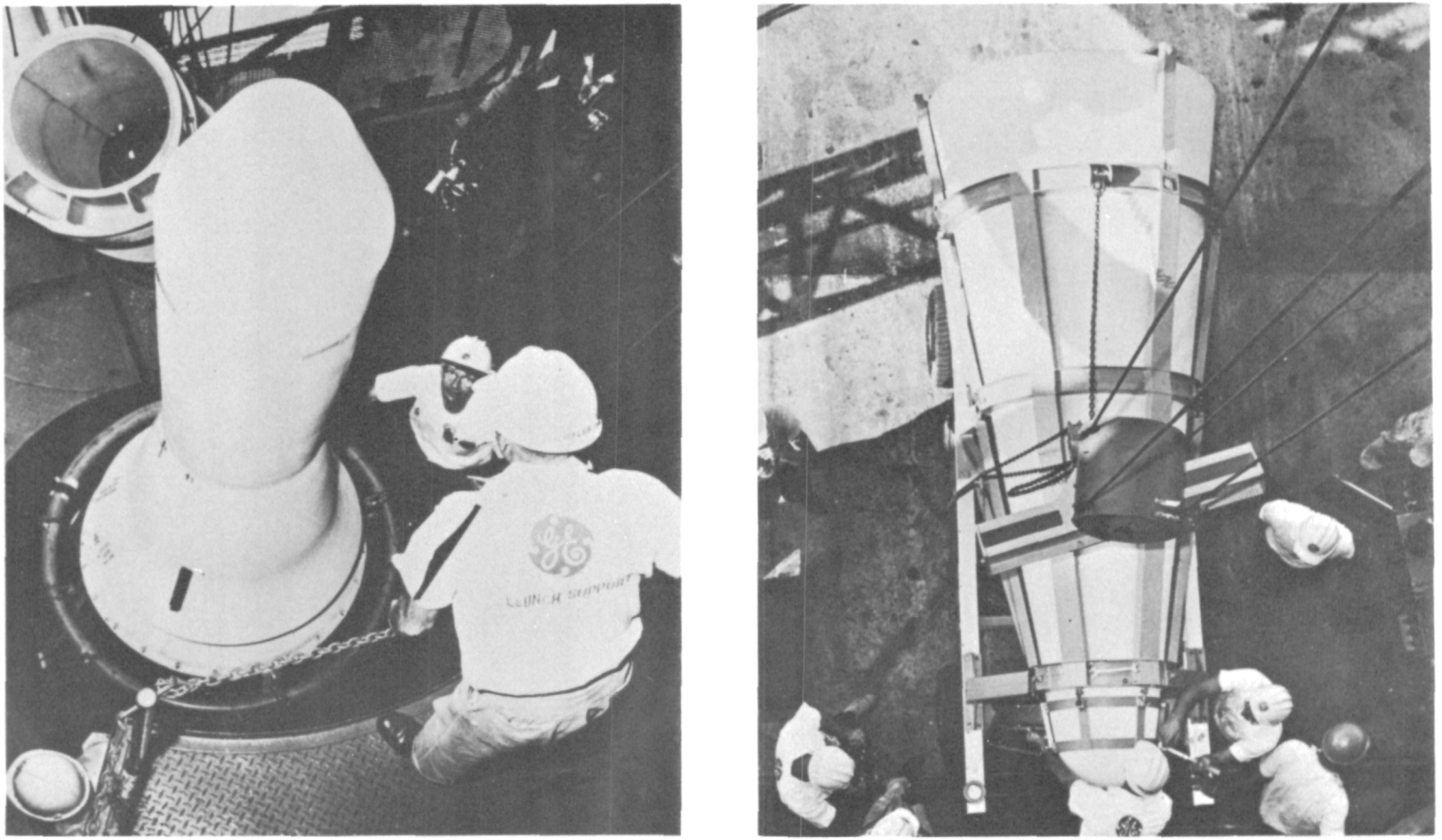

Figure B-157. MSVD flight test personnel preparing MSVD re-entry vehicles for test flight on Atlas missile

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1.3.15 Manufacturing Equipment

The MSVD manufacturing facilities and equipment are tailored to meet the specific requirements of space vehicle programs. These include general purpose machine tools found in a well-equipped shop plus more specialized machines for fabricating space vehicles. The following pictures-Figures B-158 through are a representative sample of MSVD manufacturing equipment.

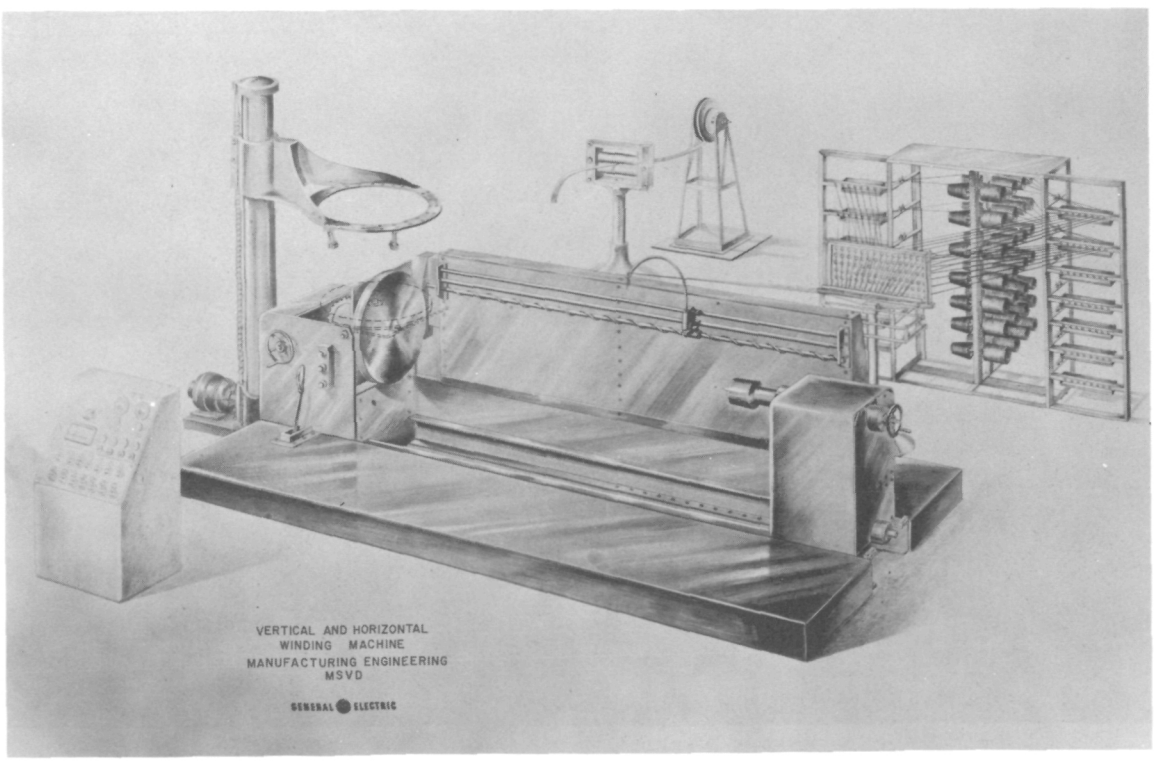

Figure B-158. Vertical-horizontal winding machine

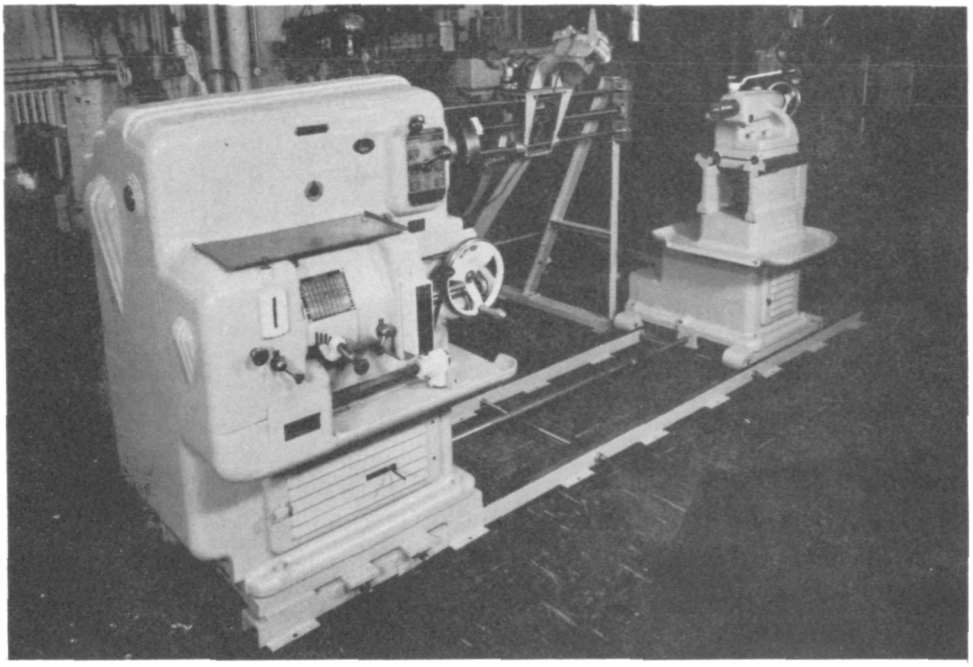

Figure B-159. Tape winding machine

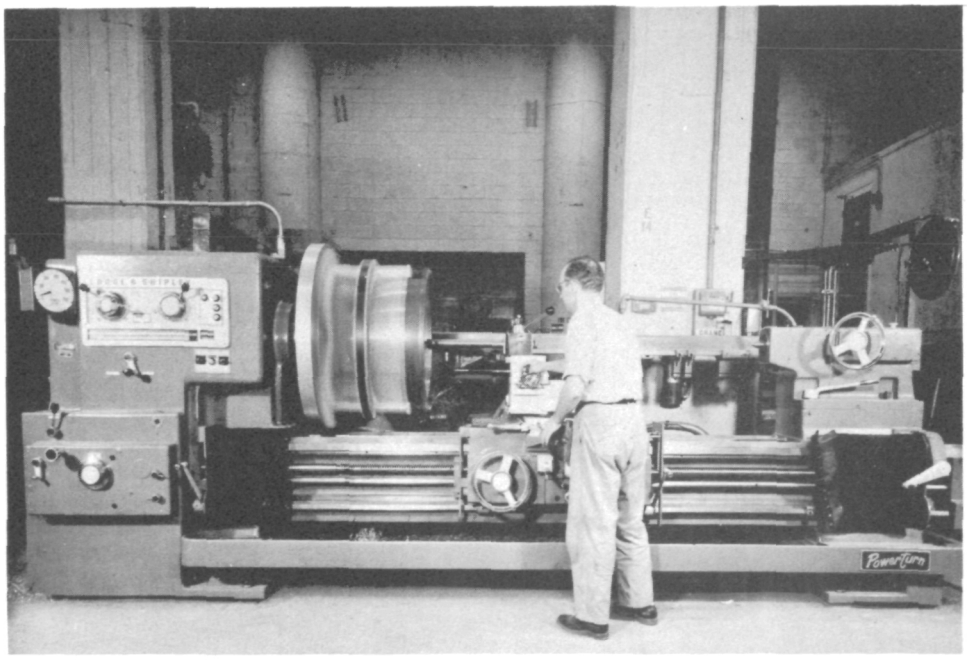

Figure B-160. Lodge and Shipley contourmatic lathe with automatic surface speed control

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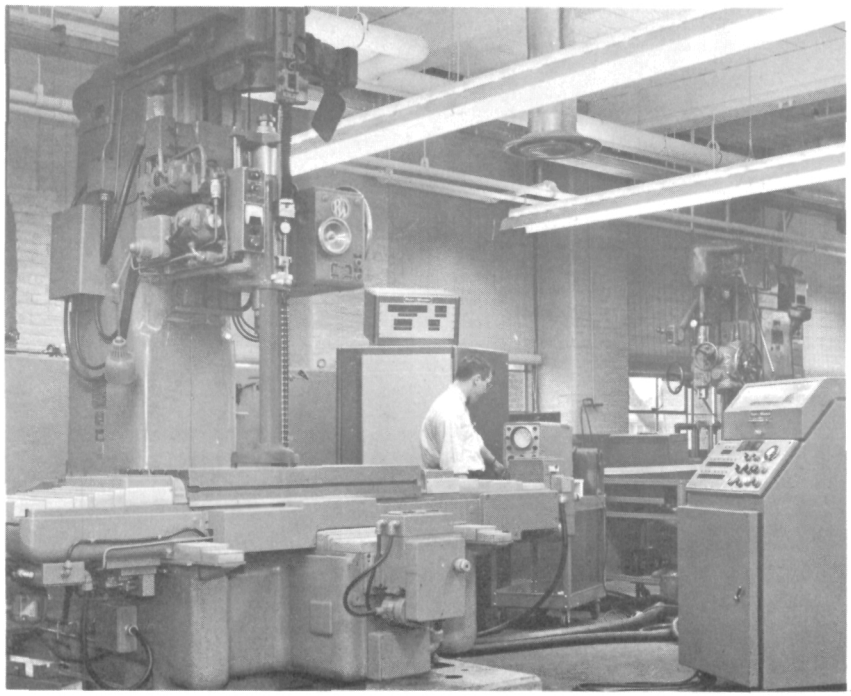

Figure B-161. Pratt & Whitney Model 2E Jig Borer with depth control. A precision numerically controlled boring machine with positioning accuracy of .00015 in./ft

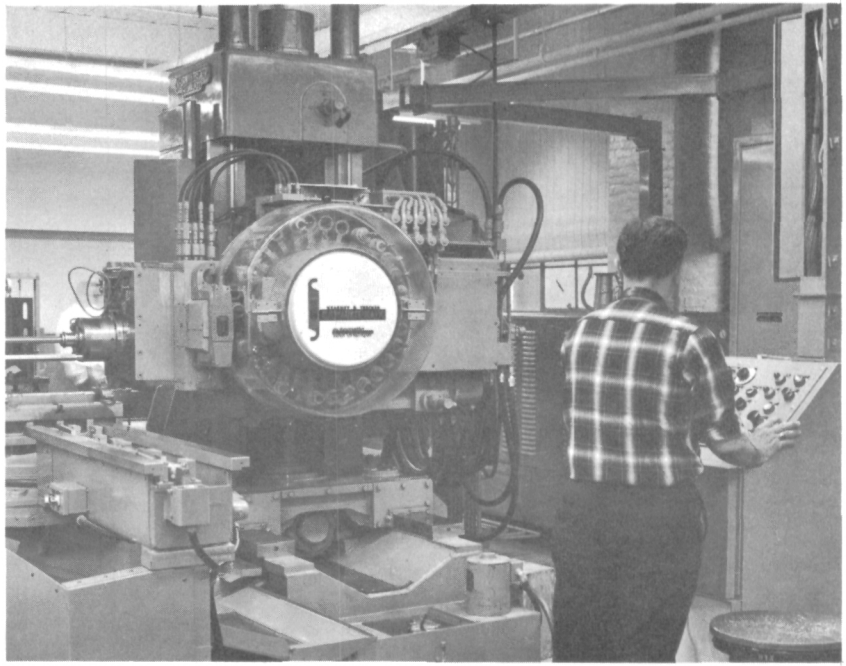

Figure B-162. Milwaukee-Matic Model #2. A Kearney & Trecker Automatic Tape controlled combination milling, drilling, boring, reaming, tapping and contour milling machine with automatic tool changer. This machine incorporates the new General Electric Mark III tape controlled program unit

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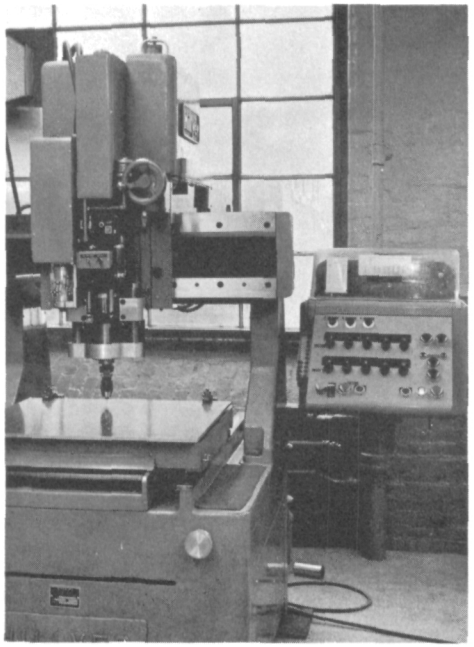

Figure B-163. Hillyer numertically controlled drilling machine

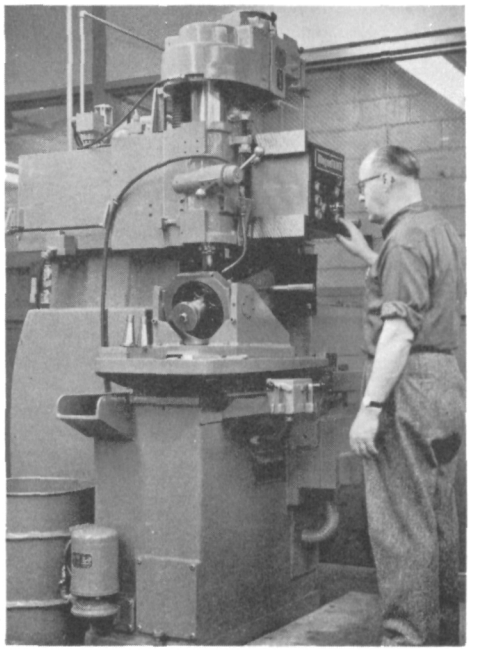

Figure B-164. New England Machine & Tool Company's Magna Trace ... milling machine with automatic two dimensional tracer control for profiling and contouring.

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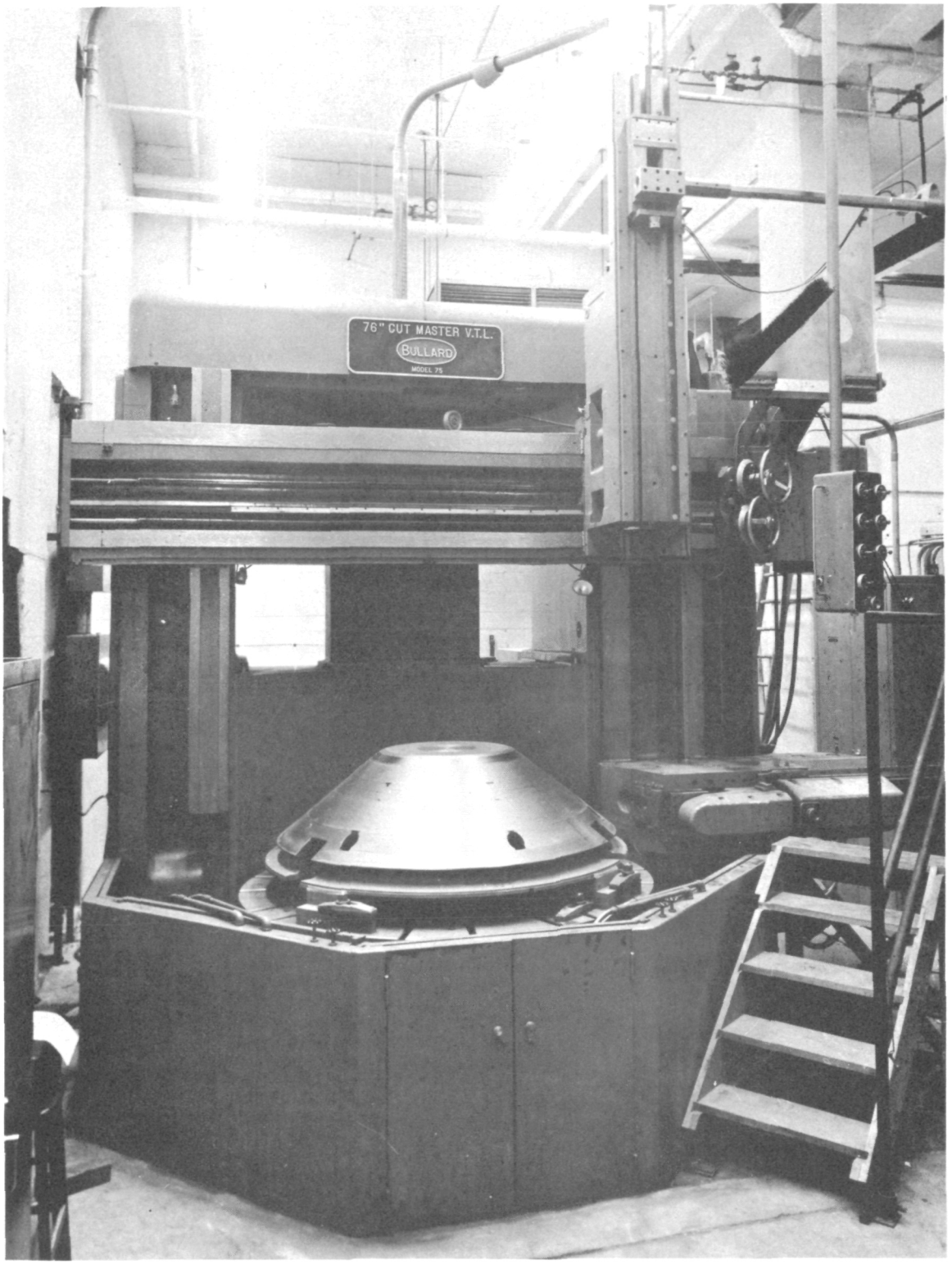

Figure B-165. 76-inch VTL with contouring features

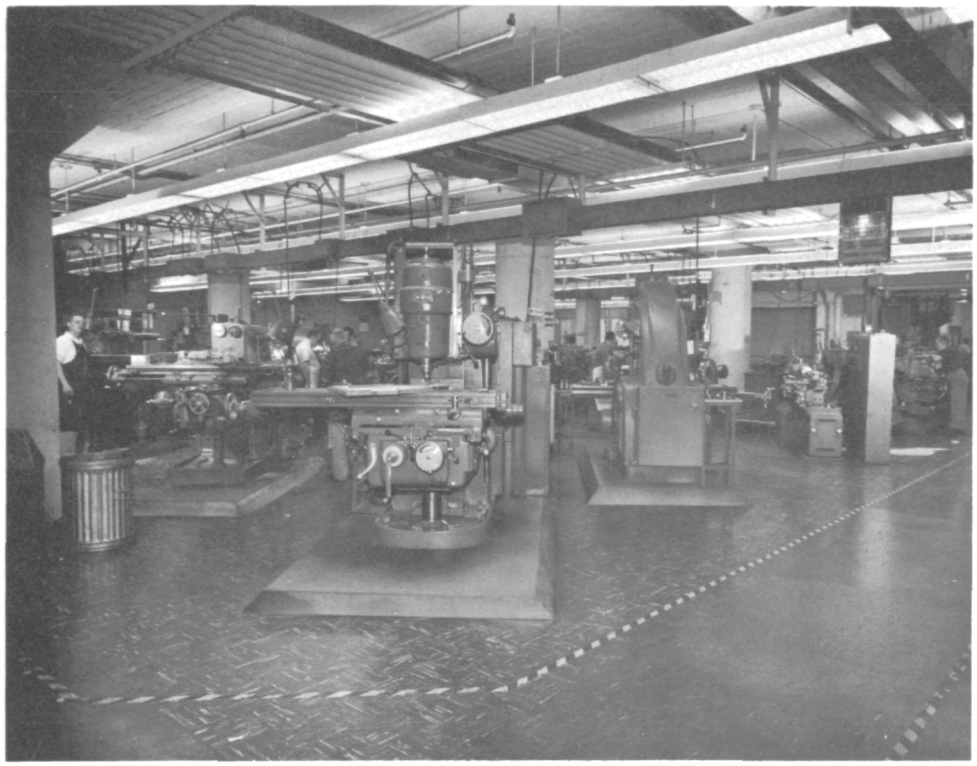

Figure B-166. View of machine shop

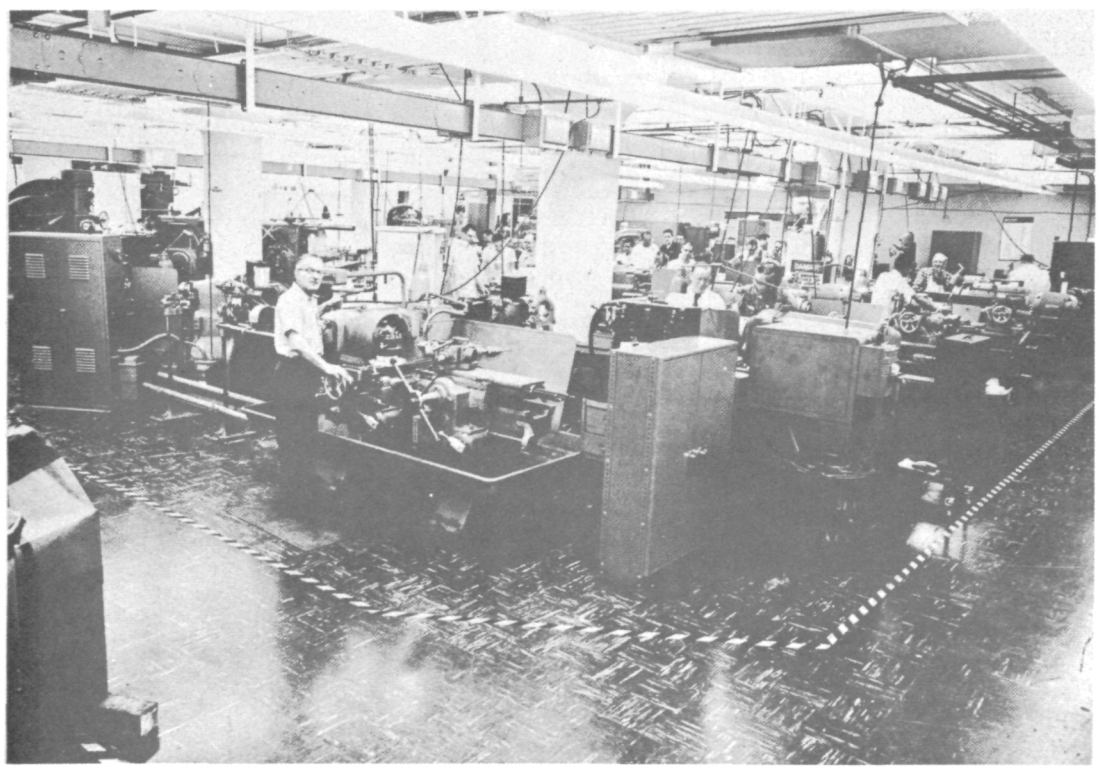

Figure B-167. General purpose manufacturing equipment

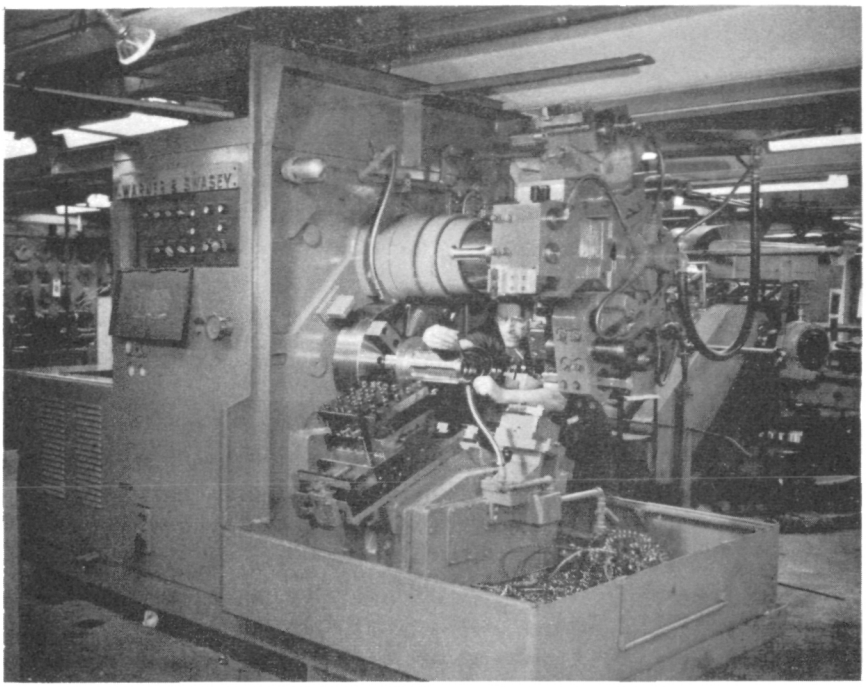

Figure B-168. Warner and Swasey single spindle automatic checking machine

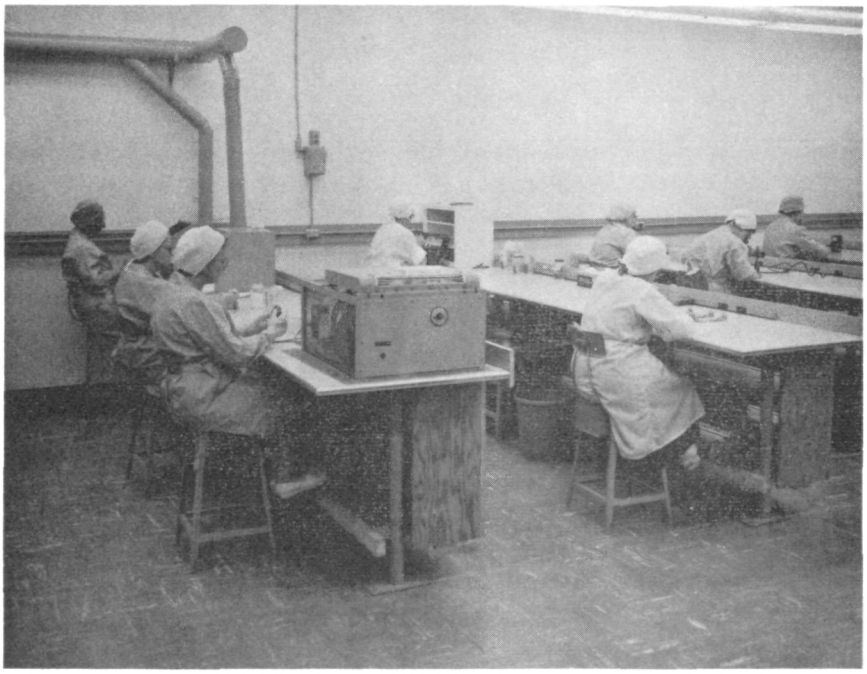

Figure B-169. Accelerometer assembly in dust free, temperature and humidity controlled atmosphere

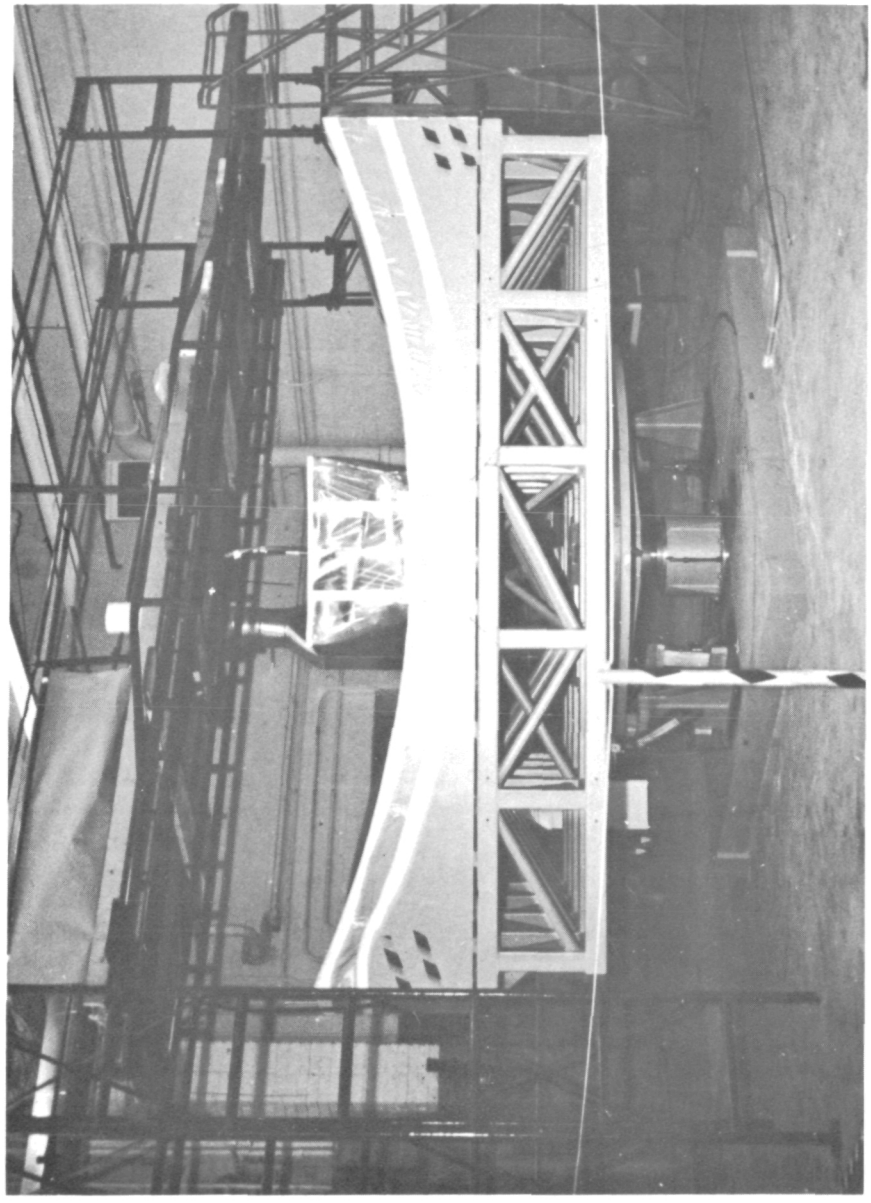

Figure B-170. Spin casting facility

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